Instruments

THE MAGAZINE OF Measurement and Control

Vol. 12
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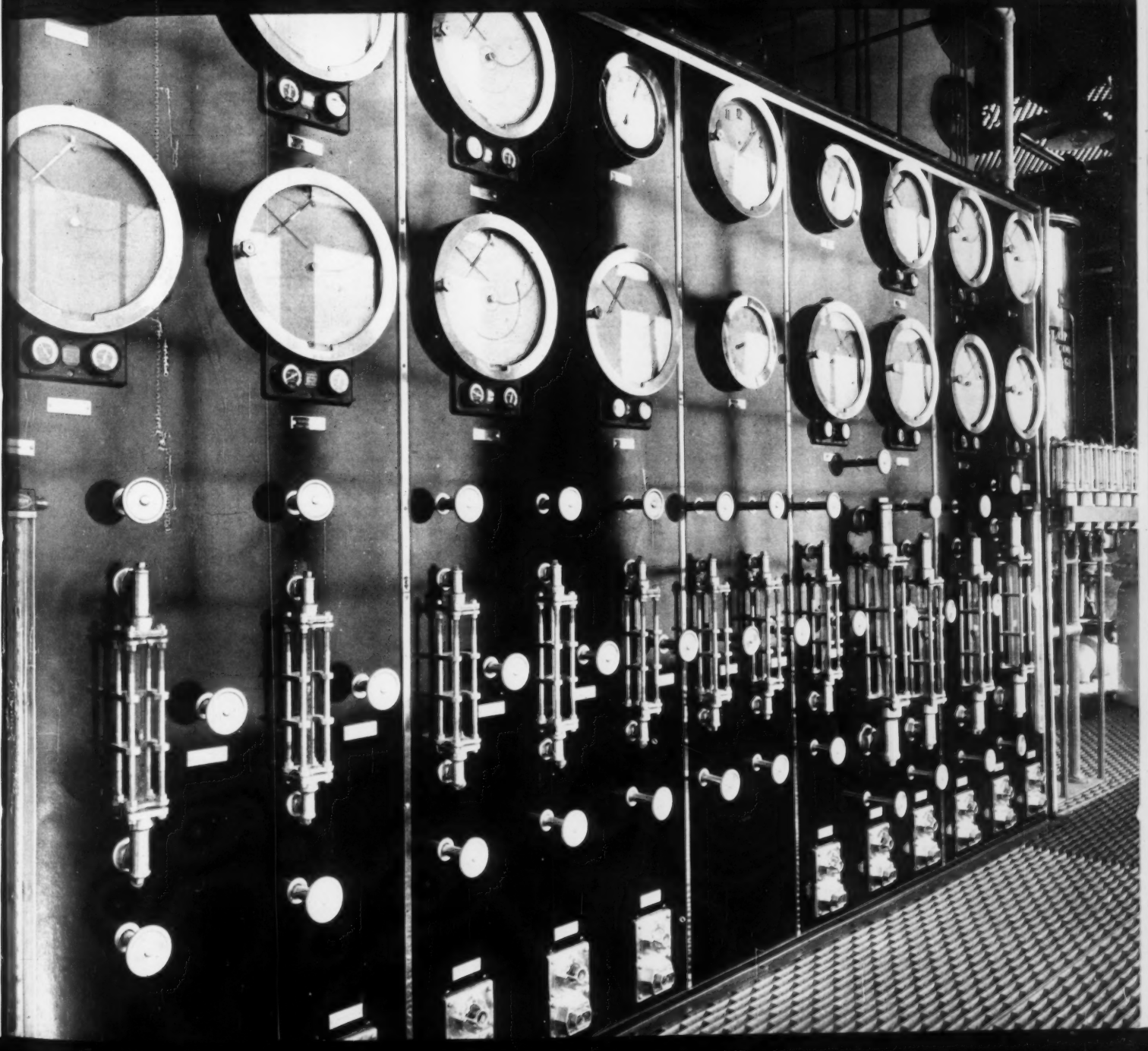
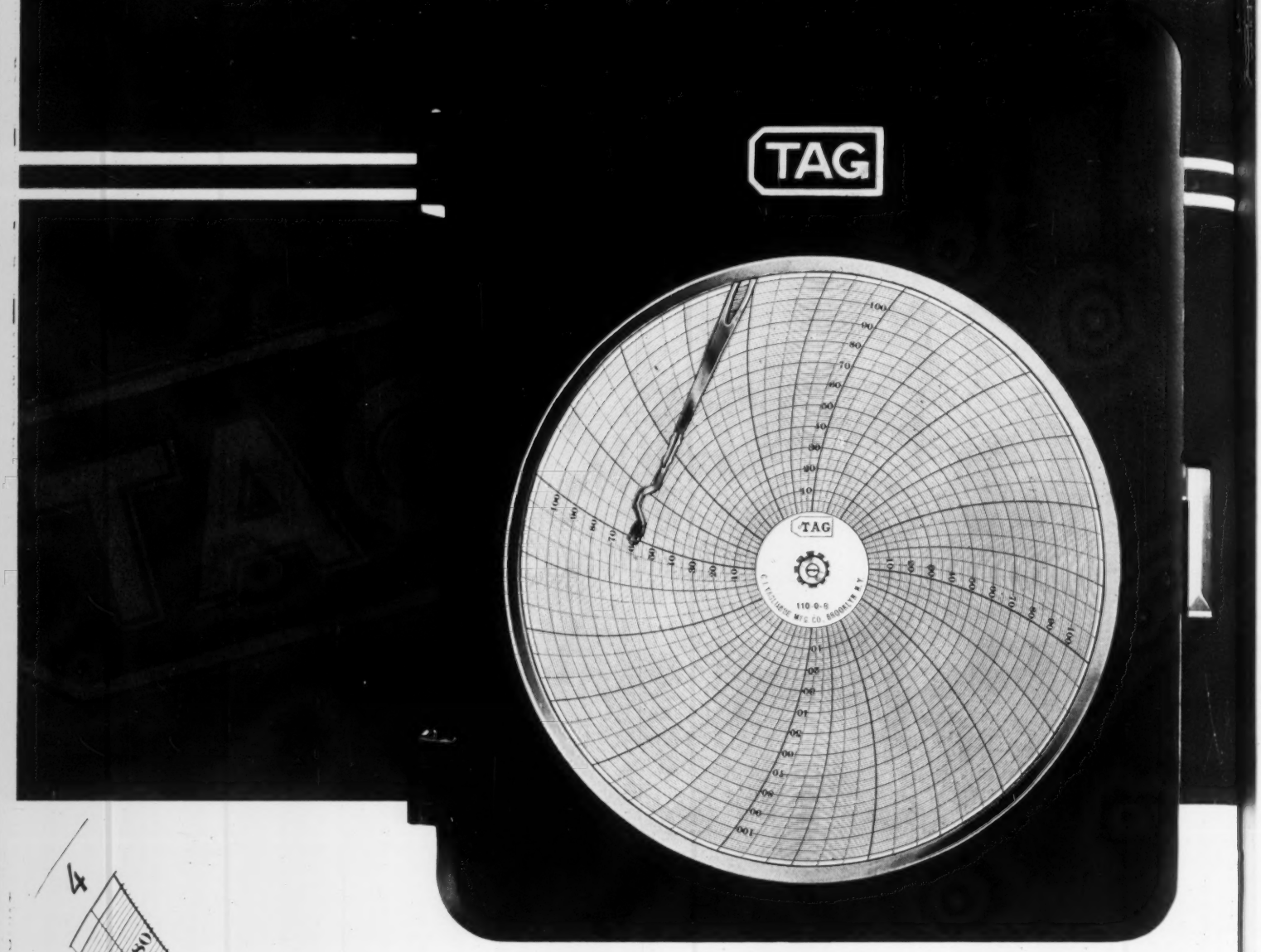
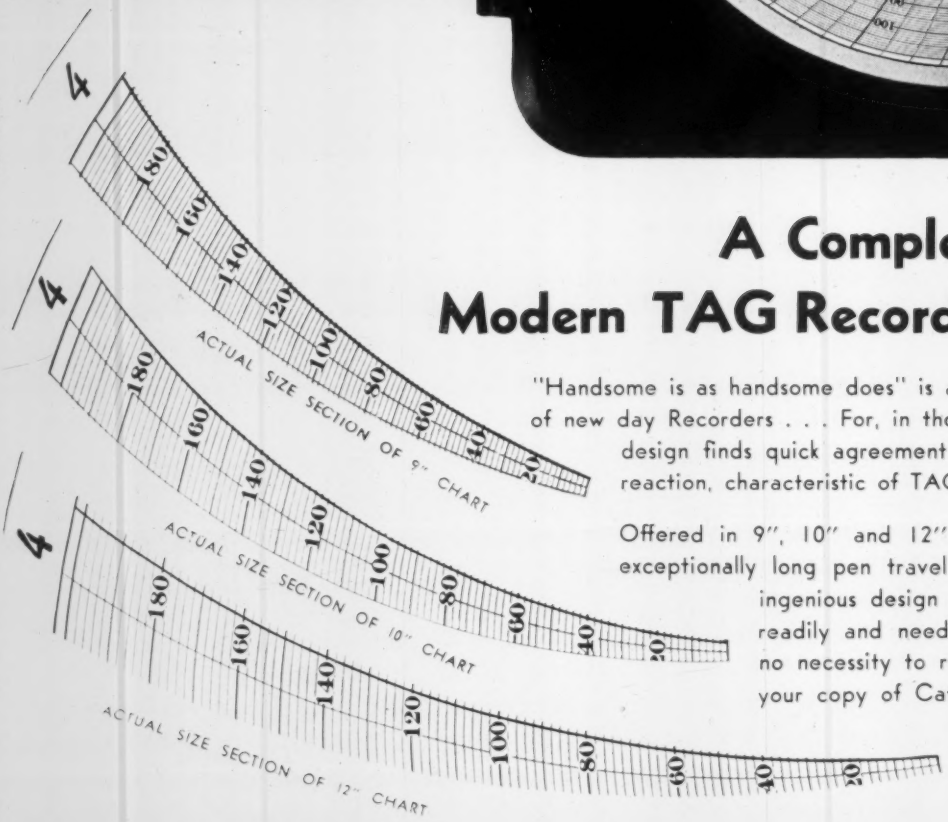
No. 4



Providing Precise Temperature Records . . . Handsomely





A Complete Line of Modern TAG Recorders with 3 Chart Sizes

"Handsome is as handsome does" is an apt description of TAG's complete line of new day Recorders . . . For, in these handsomely styled Instruments, modern design finds quick agreement with the approved standards of sensitive reaction, characteristic of TAG Temperature and Pressure Recorders.

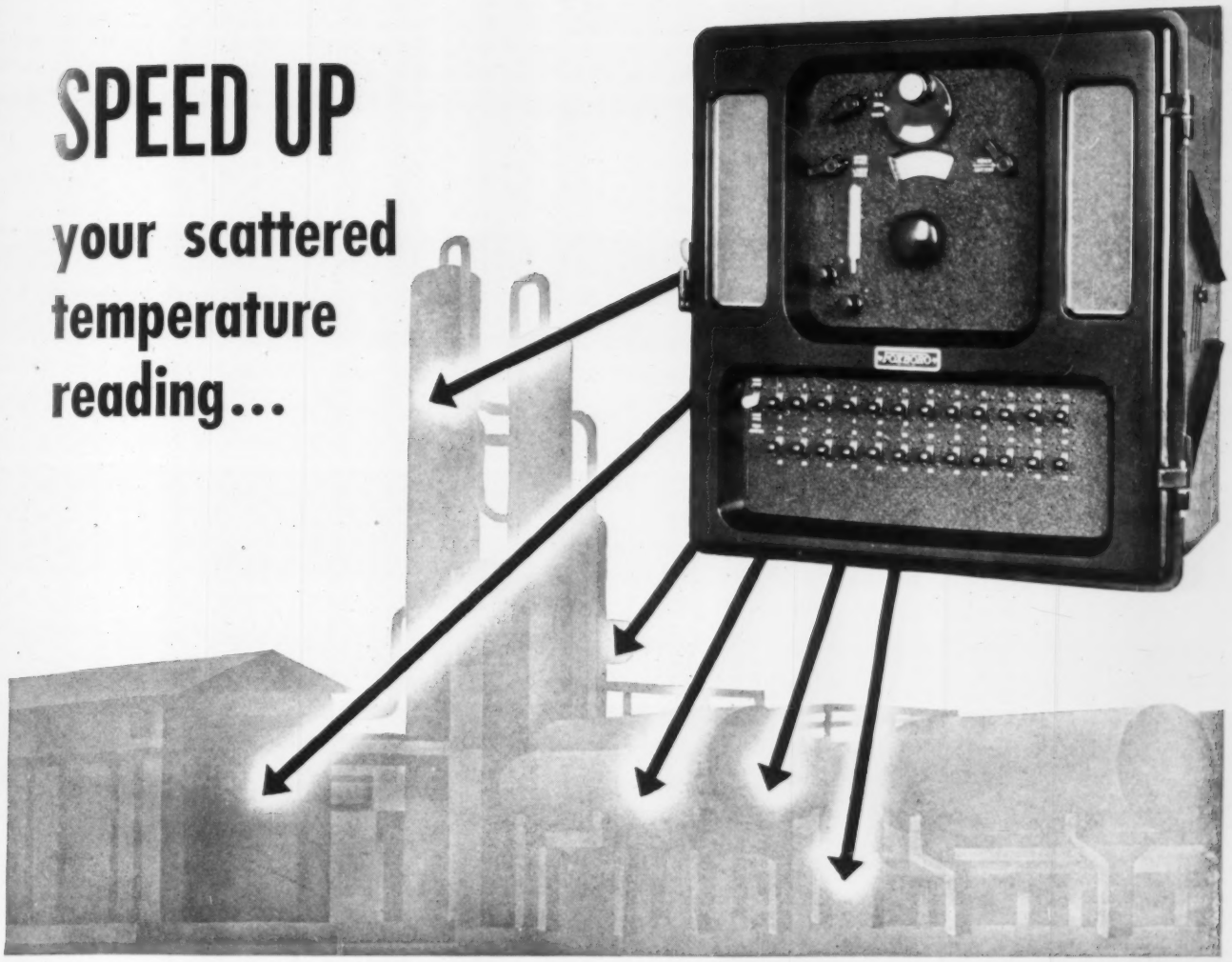
Offered in 9", 10" and 12" chart sizes, all TAG Recorders have an exceptionally long pen travel and an interchangeable tube system of ingenious design . . . the active element can be replaced readily and needs be checked at one temperature only—no necessity to recalibrate all points in the range. Ask for your copy of Catalog 1060-I which will suggest the usefulness of TAG Recorders for service and economy in your plant.

C. J. TAGLIABUE MFG. CO.

Park & Nostrand Ave's., Brooklyn, N. Y.

SPEED UP

your scattered temperature reading...



...THIS ACCURATE, CONVENIENT WAY

Many processes have numerous scattered thermocouple points from which readings must be made at definite periods. The Foxboro fast-acting Cabinet Indicator will handle as many as 82 at one central point. Readings can be made almost as fast as they can be written down. Accuracy of the indicator is guaranteed to ¼ of 1% of full scale value. » » » Operators also praise the fact that the new Foxboro Key-Switch Cabinet Indicating Pyrometer is a complete unit and easily installed. Lead wires are quickly connected to their respective terminals which are individually marked. All parts are accessible from the front. These features save installation time and money. » » » Tell us the number of thermocouples to be handled, scale range and the nature of the application. We will gladly send you detailed information. **The Foxboro Company, 46 Neponset Avenue, Foxboro, Mass., U.S.A.,** Branch Offices in 25 Principal Cities.

FOXBORO
REG. U. S. PAT. OFF.
PYROMETERS

The New
FOXBORO KEY SWITCH CABINET INDICATING PYROMETER

is a complete unit. No push button or plug and socket connections are used. Switches and rheostat are enclosed in dust-tight housing. Write for Bulletin 766 for complete details.

Fitted to YOUR JOB...

PAPER

Widest choice of paper condensers including all types and sizes of metal-can units, bakelite-case units, tubular or cartridge units, unsealed sections, etc. AEROVOX specifications call for maximum number of papers, thorough vacuum treatment and impregnation.

OIL-FILLED

Choice of several types of oil-impregnated (oil-filled) paper condensers for high-voltage, heavy-duty applications. Round-can inverted-mounted, and rectangular types. Also in wax-filled for normal-duty service.

ELECTROLYTIC

For maximum capacity and working voltage in minimum bulk and at lowest cost, the Hi-Farad line has long been the favorite. All sizes, cans, terminals, also in paper tubulars and cardboard cases. AEROVOX pioneered the dry electrolytic not only for radio but also for motor-starting applications.

"WETS"

The advantages of the wet type, notably reforming after temporary breakdown due to excessive voltages or surges, can be obtained with AEROVOX units in various types of cans. Breakdown limits can be accurately set for circuit protection purposes.

MICA

Over a dozen standard bakelite-molded mica units to choose from. Also metal-case and porcelain-case units. AEROVOX can meet the closest tolerances.

& RESISTORS

As fitting companions for its condensers, AEROVOX offers superior wire-wound vitreous (Pyrohm Jr. 10 and 25 watt) and adjustable (Sliderohm 25 to 200 watt) resistors. Also better carbon resistors in insulated-molded and bracketed types.

THERE'S more to AEROVOX than just a real good condenser. There is also the most satisfactory and economical application to your particular problem, due to A.A.E.* service.

With over a century of combined experience possessed by AEROVOX sales engineers to draw upon, and with your entire assembly studied in terms of all components and circuits, you are positively assured of the right condensers for lasting satisfaction and provable economy. It pays to remember A.A.E.*

Submit that Problem . . .

Tell us about that assembly calling for condensers, and our engineers will gladly collaborate with suggestions, specifications, samples, quotations. Meanwhile, be sure you have our catalog.

*Aerovox Application Engineering

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Instruments

THE MAGAZINE OF MEASUREMENT and CONTROL

Vol. 12 No. 4

APRIL 1939

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Engineers: E. B. Badger & Sons Co., Boston, Mass.
Photo courtesy Fischer & Porter Co., Philadelphia, Pa.

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Instruments

THE MAGAZINE OF Measurement and Control

M. F. BEHAR, Editor

In Time of War

YOU probably don't remember our April 1935 and April 1937 editorials preaching Industrial Preparedness. You may recall, however, that each was entitled "In Time of Peace." The word "peace" was technically true although the gangster governments had already begun, four years ago and two years ago, making war on the United States through spies, through hate-sowing "American citizens" and through training camps on our own soil.

On this 1939 Army Day, we need no longer refrain from using the correct word in the title; we need no longer preach Industrial Preparedness to you, fellow-American, for now you fervently desire its accomplishment. What we believe our most urgent duty is to recommend something *everyone* of you can do immediately.

It is simple, but important.

It is that you do your own job more thoroughly than ever. Your job (in nine cases out of ten) is to cut down the sum total of drudgery involved in America's industrial production, so use instruments more extensively and effectively than ever; and defend America by defending your labor-saving methods and devices against enemy agents who weaken America by anti-machine propaganda. In this connection we suggest that you send for the

Preliminary Report of American Society of Tool Engineers Fact Finding Committee Studying "Effect of the Development of the Machine on Employment and Standard of Living." By Committee, Chairman JOHN YOUNGER, Professor of Industrial Engineering, Ohio State University. Published March 1939 by American Society of Tool Engineers, 2567 West Grand Boulevard, Detroit, Mich. Paper, 8½ × 11 inches, 12 pages. Free.

which is not only a timely aid to Industrial Preparedness but an attractively presented compilation of facts. Here are a few excerpts:

W. J. Cameron of Ford Motor Co. in his radio talk of Feb. 13, 1938: "It is calculated that the cost of making a 1938 Ford car on a hand working basis would be $17,850." At such a price not more than fifty cars a year could be sold.

Walter Chrysler: "If it was decided to revert to the machine shop methods of 1900, the result would be that the yearly market for automobiles would become limited to 2428 —less than a full day's output for many of our plants."

It is like a stone thrown in a pool; the ripples reach out to the very edge . . . The automotive industry has a host of salesmen, dealers, garage men, filling stations, men designing highways, and even the little hot-dog stand proprietor along the main road owes his living directly to the automotive industry . . . Ten million new jobs created in forty years . . . Finally, behind the automotive industry lie the other great industries of steel, glass, textiles, aluminum, and lumber, all contributing a large quota of their products to the final product.

J. H. Van Deventer, Editor of *Iron Age*, in an article in the *Detroit Sunday Times*, Jan. 15, 1939: "Let me introduce one of the most spectacular processes, from the standpoint of automaticity, in the steel industry—the continuous strip mill . . . Perhaps the best illustration . . . is the growth of the use of sheet steel during the last two decades: Last year's output of 11,000,000 tons of sheet and strip was more than twice that of the boom year of 1929 and five times that of twenty years ago . . . In the last ten years, employment in companies which operated continuous mills increased 28%."

M. Court of the Automobile Mfrs.' Ass'n: "During 1937, employment in automobile factories averaged 15% higher than 1929, although production lagged 10% below 1929 levels. In 1938 employment per car increased 13% from 1937 and was 2% above 1931 levels. (1931 is the most recent year with a volume comparable to 1938.) There has been no aggregate technological displacement of labor in automobile factories despite the introduction of countless new and more productive machines and processes."

The coming of more trades schools, the coming of more manual training courses in our high schools will do much to make our new population more flexible in their training and education, so that they can be fitted for different kinds of jobs. [See article on evening-school training of instrument men, on page 110 of this issue—EDITOR]

Another recent development worthy of support by our readers in executive positions is the American Conference on National Defense, of which Gen. Samuel McRoberts is Chairman and Col. F. H. Payne Vice-chairman.

And—as in 1935 and 1937—we urge your joining the Army Ordnance Ass'n (now celebrating its 20th anniversary). Its address is Mills Bldg., Washington, D. C. Only $4, including its fine magazine.

April and May Technical Meetings Featuring Instrumentation

ELECTRIC METERMEN'S CONFERENCE

Electrical Engineering Dep't, University of Illinois, Urbana, Ill., April 19-20-21.

Circuit Theory. (Six parts, one each morning and afternoon)—E.E. faculty members.

What makes the Disk Go 'Round (Two parts)—D. T. Canfield, Purdue University.

Use, Care and Accuracy of Indicating Instruments.—C. Miller, Weston Elec. Inst. Co.

Testing Polyphase Meters.—Westinghouse lecturer.

G-E film, "When You Can Measure."

Maintenance of Demand Meters.—R. H. Posey, Pub. Service of N. Illinois.

Importance of Analyzing Industrial Loads.—M. F. Behar, Editor *Instruments*.

Current Diversion.—H. M. Brown, Pub. Service of N. Illinois.

Customer Relations.—F. A. Ferguson, Commonwealth Edison.

Kva and Reactive Metering. Application of Lightning Arresters to Meters. (Lecturers to be announced.)

Numerous other features, at luncheons, dinners and evenings. For complete details, write to Elec. Eng. Dept., Univ. of Illinois, Urbana, Ill.

SYMPOSIUM ON "WATER"

American Chemical Society, New York Section, Hotel Pennsylvania, New York City, 6 p.m., Friday, May 5 (dinner precedes meetings).

General speaker, H. E. Jordan, Am. Water Works Ass'n.

Organic & Biological Sec. lecturer, Jacques Bourdillon, Rockefeller Institute.

Ind. & Eng. Sec. lecturer, F. Bachmann, The Dorr Co.

Phys. & Inorganic Sec. lecturer, M. F. Behar, Editor *Instruments*.

TENTH ANNIVERSARY MEETING OF THE ACOUSTICAL SOCIETY OF AMERICA

Hotel Pennsylvania, New York City, Monday and Tuesday, May 15 and 16.

"A program of outstanding interest" which will include a *Symposium on the Measurement and Application of Absorption Coefficients*. Statement of the Problem—F. V. Hunt, Harvard University. Measurements in the Reverberation Chamber—P. E. Sabine, Riverbank Labs. Measurements in the Field—G. T. Stanton, Electrical Research Prod. Inc. Open Discussion led by V. L. Chrisler, Bureau of Standards, John Parkinson, Johns-Manville Sales Corp.

Other papers of unusual interest will be presented. Requests for the final program should be sent to the American Institute of Physics, 175 Fifth Avenue, New York City.

THE MONTH'S NEW INSTRUMENTS

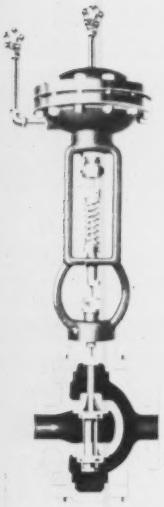
In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Pump Governor

Improved by-pass or relief type of pump pressure governor, designated as "Type 115," is especially designed to maintain differential pressure setting of system by relieving excess pressure in discharge back to suction side. It is installed in line connecting discharge of pump with suction; is suitable for differential pressures ranging from 10 to 100 lbs. in.², and for working pressures up to 1000 lbs. in.², 100 F., is spring-controlled and said to be especially suitable for installation in vertical pipe lines. Calibrated steel spring which opposes differential pressure on diaphragm is, said to give easy throttling control over boiler feed pumps. Other features include full-capacity valves; globe bodies that can be readily inverted; anti-friction deep-gland stuffing-box guides for stem; needle valves in the control pipe; balanced inner valve connected to the valve stem by "Fisher's patented Flexaline" connection. *Fisher Governor Co., Marshalltown, Iowa.*

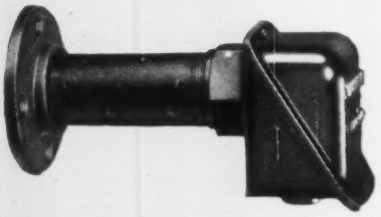


Wire-wound Rheostats

Low-power wire wound controls and rheostats are announced "in all needed ranges up to 10,000 ohms," are equipped with "Silent Spiral Connector" (see *Instruments*, November 1937, page 2751. Power dissipation is 2 watts. Units are available with or without switch and with a complete assortment of shaft variations. Dimensions are 1¼" diam. × ⅞" depth of case. *International Resistance Company, 401 N. Broad St., Philadelphia, Pa.*

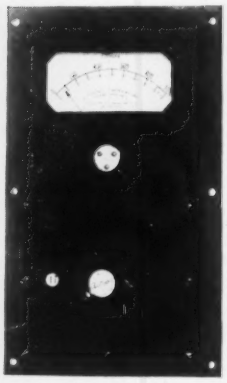
Cumbustion Safeguard for Luminous-flame Failure

Designed for fuels other than gas, burning with luminous flames, new "Photo-Head" comprises a photocell and filter, therefore responds to characteristics of a luminous flame but not to heat radiation from incandescent walls of combustion chamber; and acts instantly upon failure of flame of fuels other than gas. "Photo-Head" is an adjunct to "Wheelco Flame-Otrol" combustion safeguard; it is used instead of electrode utilizing flame conduction principle in other models. *Wheelco Instruments Co., 1929 S. Halsted St., Pilsen Sta., Chicago, Ill.*



Multi-point Pyrometers

New Series "2800" flush-mounted rectangular type multi-point pyrometers are available with selector switches for 8, 17, 25 or 28 points, arranged for back or bottom conduit connection. New models are similar in most respects to maker's other switchboard type multi-point pyrometers (*Instruments*, August 1936, page 2191. *Illinois Testing Laboratories, 420 N. La Salle St., Chicago, Ill.*

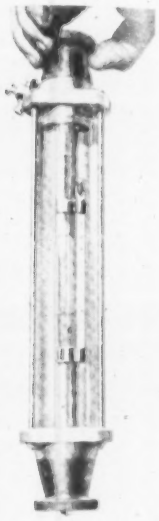


Portable Self-contained Recording Thermometer

Dimensions of new "No. 70 Serviceman" Recorder 5" × 6" × 2¼", weight is less than 2 lbs. Primary measuring element is a bimetallic spiral "of advanced design." Zero adjustment is by a screw which follows idea of maker's "Recalibrator." Chart drive is adjustable clock movement, wound by knob extending through back of case. Pen arm has a friction hinge which permits it to be swung clear of chart. A pointer on dial enables operator to set chart at proper time. Dust-tight case is smooth cast-aluminum, finished in satin black, with polished chrome bezel. Instrument comes packed in a hinged container which also contains a supply of charts and ink. If desired, a leather carrying case is available. Available F. and C. charts cover room temperature, outside temperature, cooling and heating applications. *Jas. P. Marsh Corp., 2163 Southport Ave., Chicago, Ill.*

Multi-range Viscosimeters

Steiner Viscosimeters are announced in rising-air-bubble and in falling-ball types covering viscosity ranges extending from 0.01 to 1,000,000 centipoises and temperature ranges from −35° C. to 320° C. Each instrument consists essentially of a calibrated tube (approx. 10" long) of special glass, surrounded by a glass jacket, in which 210 cc. of glycerin serve as the temperature bath. Volume of sample need not be greater than 6 cc. (5 cc. for waxes; etc.). A thermometer of appropriate range is affixed to each measuring tube. Determinations are made by turning entire instrument end over end and timing rise of bubble or fall of cylindrical or spherical body; can be repeated immediately by again inverting instrument. Temperature-viscosity curves can be obtained in 10 min., comprising eight times more points than are taken when using customary methods requiring hours. Twelve standard models are available, covering all major needs of industrial plants and laboratories; special models can be made up. Special graph papers are available from stock, including ASTM standards, etc. *The E. J. Fenner Co., 131 State St., Boston, Mass. Campana, Springfield, Mass.*



Electron Tube Testers

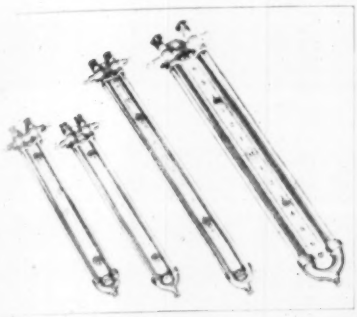
Maker's dynamic mutual conductance tube testing equipment including Models No. 51-X, T 53 P, T 53 C and 5348 has been revised to test Loktal tubes, ballast tubes, 50 volt tubes and pilot lamps. Also have noise tester. All of these instruments give dynamic mutual conductance readings in micromhos as well as indicating, "good, doubtful replace." *The Hickok Electrical Instrument Co., 10514 DuPont Ave., Cleveland, Ohio.*

Vacuum Indicator-controller

New Model 20 "Tru-Vac" is an all-a operated Pirani or hot-wire type of vacuu gage (see *Instruments*, Sept. 1931, pa 518; July 1934, page 1181, equipped wi self-contained amplifier and relay with a carrying capacity of 10 amps. at 110 volts. Relay is fully automatic and will start o stop vacuum pumping operation at any predetermined pressure. *Continental Electric Co., Geneva, Ill.*

U-tube Manometers

Universal L Gauge or Manometer is [illegible] for portable or stationary use, for [illegible] pressure or differential, is [illegible] with ⅜" or ½" "glass-like un-



breakable tubing" in eight sizes from 6" to 36", plain or fitted with valves for portable use and as a differential gage. Specially constructed models are also available for use as mercury gages. Among the features are: tubing fitted with standard pipe threads so tubes can be screwed into metal attachments without packing glands or gaskets; needle valves at top to retain fluid for portable use; tubing withstands 100-lb. pressure; scales movably attached for zero adjustment; drain valve at bottom of gage.—*Chicago Iron Sponge & Governor Company, 2137 S. California Ave., Chicago, Ill.*

Frequency Meters

To maker's line of 4" square-case electrical indicating instruments is added a series of frequency meters comprising four models,

all with 55-65 cycle ranges but for voltages of 120-125, 125-150, 200-225 and 225-250. Mechanism is electromagnet type; scale length is 3 ½"; accuracy is ¼ cycle; net weight 9 lbs.; external reactor box.—*Rollers-Smith Co., Bethlehem, Pa.*

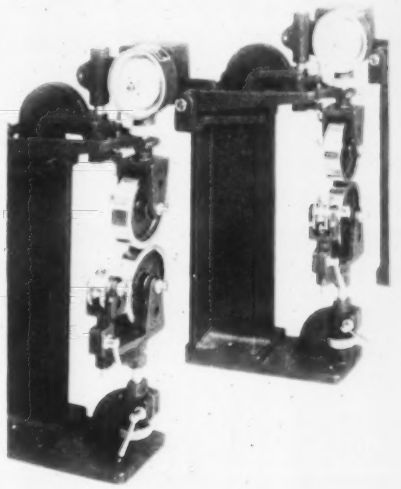
Roller-leaf-spring-actuated Micro Switch

New roller-leaf-actuated Micro Switch is designed for service in applications as follows: where small moving power is available to make or break circuits; requiring low friction and minimum change of operating point through wear; and where roller action is needed between cam and switch lever, such as control of motors, heaters,

solenoids, etc., from cams, slides, or rolls. Overall dimensions 2½" × 1⅝" × ¾" wide. Handles ½ h.p. Either "Standard" or "Type Z" mechanism can be obtained with new roller leaf actuator, also "Metal-Clad" housings. Sep. switch can be obtained with normally-open, normally-closed, or d-t. contact arrangements. Underwriters' listing.—*Micro Switch Corp., Spring St., Freeport, Ill.*

Continuous Measuring Gage for Wire or Flat Material

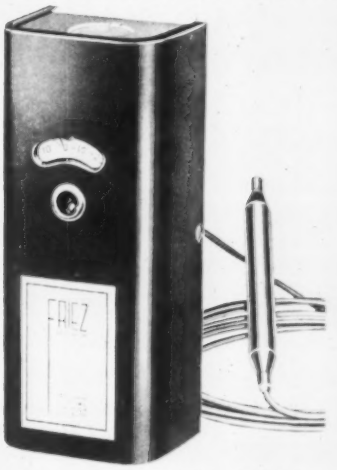
"Model 193 B-21" supplants old "No. 1253" and is available with roller contacts as illustrated or with solid anvils of steel



or tungsten carbide. Roller-contact design and construction are high-precision, permit speeds of 1000 f.p.m. with 1" rollers. Optional equipment: (1) floor stand, (2) recording gage.—*Federal Products Corp., 1144 Eddy St., Providence, R. I.*

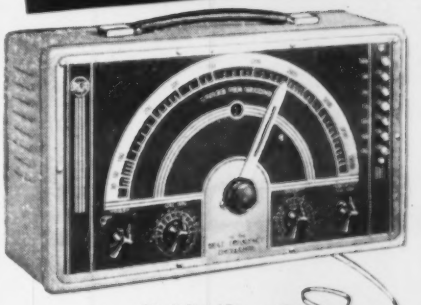
Refrigeration Controllers

For controlling temperatures of refrigerated enclosures such as food display cases, beer coolers, "walk-in" commercial refrigerators and similar applications operating



within ranges from —20° to +75° F., a series of temperature controllers and pressure controllers has been brought out, comprising nine temperature-control models all with liquid-filled thermal systems, three pressure-control models and one combination or duplex temperature and pressure model. Illustration shows "Type HR-65" temperature controller which has —30 to +30° F. setting scale, 2° fixed differential, 8 ft. capillary, key adjustment, 2-wire, single-throw switch, load capacity 25 amp. at 120 volt and equivalent.—*Julien P. Friez & Sons, Baltimore, Md., 2 Central Ave., Baltimore, Md.*

NEW ★ RCA BEAT FREQUENCY OSCILLATOR



Stock No. 154

$49.95 NET

Provides a variable frequency source of alternating current from 30 to 15,000 C. P. S.

For fidelity checking of audio amplifiers and radio receivers, this fine audio oscillator will be found unexcelled. It also may be used as a source of a-c for making bridge measurements where low distortion is required and several frequencies desirable. In conjunction with a stroboscope, it is useful for checking speeds of moving mechanical parts. As a sweep frequency for a Cathode Ray Oscillograph, it gives accurate measurements of vibration frequencies when used with the RCA Vibration Pickup. Many other diversified applications.

SPECIFICATIONS

Output Frequency
50-15,000 cycles (—1 db from 50 to 10,000 cycles, down 2 db at 15,000 cycles).

Output Voltage
Open circuit . . . 37.5 volts
5000 ohm load . . . 25 volts
500 ohm load . . . 7.5 volts
250 ohm load . . . 5.2 volts

Power Output . . . 125 milliwatts

Distortion
less than 5% rms over entire range

Comes with snap handle for easy carrying. Further information may be obtained from all RCA Parts Distributors or by writing to the address below.

Listen to the Music Hour of RCA Victor Sunday, 2 to 3 P. M., E. S. T., on the NBC Blue Network.

For finer radio performance . . . RCA Victor Radio Tubes

RCA Test Equipment

RCA Manufacturing Co., Inc., Camden, N. J.
A Service of the Radio Corporation of America

All-ferrous Construction Pressure Gages

All-welded all-ferrous construction of new "Model F" indicating gages affords protection on applications where there are fumes or vapors corrosive to bronze; and

absence of solder and bronze eliminates fire hazard. A special Chapmanized steel of high Brinell rating is employed in pinion, segment, arbor and connecting link. Segments and pinions have milled teeth. Movement plates, columns, links, shoulder screws, pointers and dials are of stainless steels. 270° Bourdon spring is said to permit use of springs double range of gage without increasing movement multiplication or decreasing accuracy. Chrome molybdenum steel is used for ranges up to 1,000 lbs.; above that, nickel steel. "Model F Test Gage" is available in ranges from 0-15 lbs. to 0-10,000 lbs.; its accuracy guarantee is 0.5% at any point on range. "Model F Refinery Gage" (0-60 lbs. to 0-2,000 lbs.) and "Model F Hydraulic Gage" (0-600 to 0-10,000 lbs.) are guaranteed accurate within 1% of total range.—*The Foxboro Co., Foxboro, Mass.*

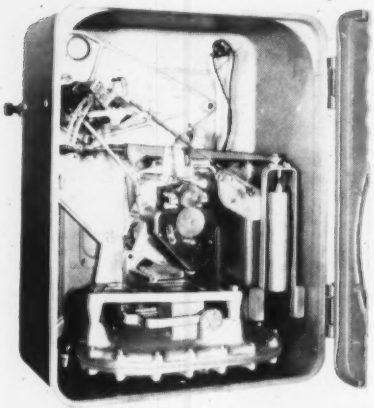
Electrode Assemblies

Two new pH meter electrode assemblies especially designed for industrial applications are announced: (1) Flow Type Electrode Assembly can be incorporated in pipe

ing for direct measurement of pH fluctuations on solutions in process, consists of a porcelain enameled flow chamber with standard 1" inlet and $\frac{3}{4}$" outlet pipe connections. Electrodes and temperature compensating thermometer are held in a stainless steel cover plate; gaskets are said to permit "moderate" pressures. (2) Immersion Type has its electrodes mounted in a stainless steel plate and guarded by a framework of stainless steel rods. A stainless steel hood keeps electrode connections dry and a $\frac{3}{4}$" connection accommodates any length of standard pipe for immersion to whatever depth is desired. In both assemblies, electrodes are internally shielded against electrostatic interference and can be supplied with leads up to 500 ft. for remote installations.—*National Technical Laboratories, 3329 E. Colorado Blvd., Pasadena, Calif.*

Diaphragm Type Air-flow Element for Boiler Meter

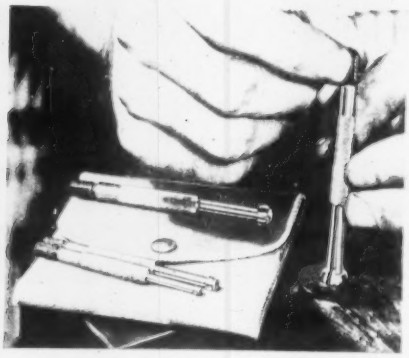
Development of a diaphragm-operated air flow mechanism for meter's standard Steam Flow-Air Flow Boiler Meter simplifies meter's application to steam generating



units by permitting air flow connections to be made at locations in economizers, air heaters, or boilers where high draft conditions preclude use of usual oil-sealed air flow mechanism. New mechanism employs a moisture-proof heat-resistant treated-silk diaphragm clamped between flanges of a metal housing. Air flow connections are made to both sides of diaphragm, and differential is recorded (in blue ink) in terms of air flow, being coordinated on boiler meter chart with red-ink steam flow record so that coincidence of these records on the chart denotes ideal combustion conditions. In addition to recording air flow and steam flow, boiler meter may also record flue gas temperature in green ink. Meter is arranged so that records may cross one another and so that steam flow and air flow records may coincide without pens interfering.—*Bailey Meter Co., 1054 Ivanhoe Road, Cleveland, Ohio.*

Small Hole Gages

Designed for measuring small holes and internal dimensions less than those ordinarily handled with telescoping gages, new No. 829 gages are available in sets of four gages



covering the ranges $\frac{1}{2}$" to 2-10", 2-10" to 3-10", 3-10" to 4-10" and 4-10" to $\frac{1}{2}$". End of each gage is in the form of a split ball which is expanded by a cone controlled by knurled knob at end of handle. Ball is placed in hole, expanded to get the "feel" and measurement transferred to a micrometer.—*L. S. Starrett Co., Athol, Mass.*

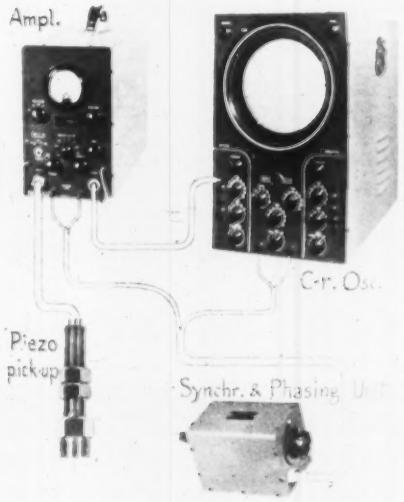
Dial Indicators

Claim that four new dial indicators are "the most accurate and most sensitive" is explicitly made in manufacturer's announcement, and quantitative guarantee is given. Example, for 0.02" spindle travel: "0.00002" accuracy and 0.00001" sen-

tivity. This applies to all four sizes, which are (O.D. of dial) 1½", 2⅛", 2¾" and 3⅜". Design and construction features include "perfect tooth forms" in wheels and pinions, thick-section machined brass cases, shadowless cup dials, carbide tipped contact points and natural-sapphire jewel bearings for all staffs.—*B. C. Ames Co., Waltham, Mass.*

Engine-indicator System

For designers, manufacturers and testers of high-speed internal combustion engines, new electrically-operated engine-indicator diagram equipment permits measurement of rapidly changing cylinder pressures. It is composed of a piezoelectric (quartz crystal type) pressure unit, a cathode-ray oscillograph, an amplifier, and a synchronizer unit. Pressure unit is unaffected by temperatures up to 350° C. and built to withstand pressures up to 5,000 lbs./in.². Its accuracy is said to be "high at engine speeds over 1000 r.p.m. on four-cycle engines. For engine



speeds under 500 r.p.m., the unit is not recommended." Synchronizing and phasing angle-setting unit is said to permit simple and accurate orientation of any point on diagram with respect to crankshaft angle. Equipment as a whole is said to permit simple electrical calibration of pressure at any point in pressure diagram; and the observation of complete engine-cycles in single curve, or detailed study of any portion of a cycle.—*RCA Mfg. Co., Camden, N. J.*

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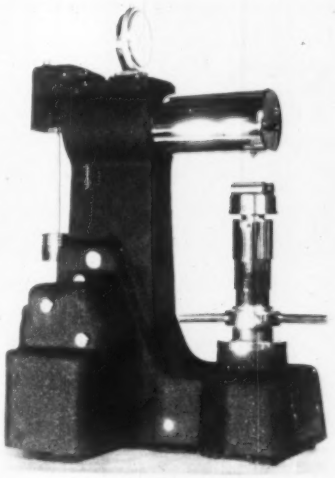
Hardness Testers for Internal Surfaces

New "Model 3-CR" Rockwell Hardness Tester and "Model 3-CS" Rockwell Superficial Hardness Tester are designed for internal testing of large tubes and cylinders.

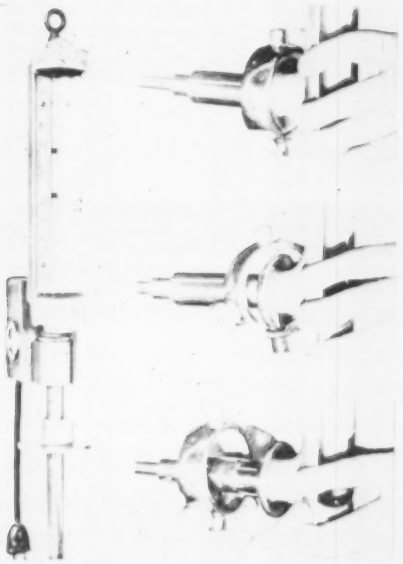


Piece being tested is projected over horizontal testing arm. Machines can also be used for testing outer surfaces. These models are made in an 8" vertical capacity, 6" horizontal reach, and will test internal surfaces down to 4" I.D. Sensitivity and accuracy of these special models are same as in regular line and they have same construction. Operation is semi-automatic through motor operation. Standard Rockwell readings are obtained.—*Wilson Mechanical Instrument Co., Inc., 383 Concord Ave., New York City.*

Dairy Thermometers

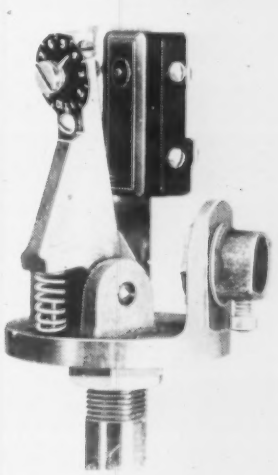
(1) New Alarm Thermometer for Pasteurizers is said to be "two thermometer systems in one"—mercury-in-glass, and electric-contact system which rings bell when milk reaches proper temperature. Installation consists in removing old thermometer putting new one in its place and plugging socket into electric supply line.

(2) New removable union nut complying with new ruling of International Ass'n of Milk Sanitarians. Three right-hand illustrations show method; accomplished without necessitating re-design of thermometers.—*Consolidated Ashcroft Hancock Div., Manning, Maxwell & Moore, Bridgeport, Conn.*



Fixed-stem, Snap-action Temperature Controller

New single-switch "Model V-I Heat Control" is designed as a companion to the two-switch model "Model VD-II" (see *Instruments*, Feb. 1938, page 59). Stem tubes are



available in aluminum for air, chromenickel for liquids, in lengths up to 23½", with a choice of ratios of sensitive portion to insulation-and-extension portion. Ranges of all models extend from 100 F. to 600 F. Individual ranges, their adjustments and operating differentials vary inversely with individual instruments' tube lengths. Snap-action switches: 10 amps. 110 volts, 5 amps. 220 volts or 2 amps. 110 volts non-inductive load, or ½ h.p. 220 volts, all a.c.—*Bucking Instrument Co., 241 Springfield Ave., Newark, N. J.*

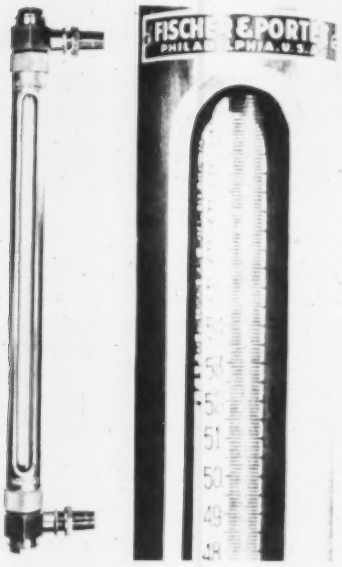
Industrial Process Timer

Vernier setting, whereby time cycles can be set to tenths of least scale division, is chief feature of new "Series 2800 Type 2802" timer for industrial processes, auto-

matic machinery and research-laboratory work. Four arrangements of lead circuits can be effected, the resultant possibilities being so varied that maker describes them by means of tabular and symbolic presentation (in Section F of Bulletin T-20). These lead-circuit changes are made without tools and without dismounting timer: by adjusting slides and by locating bridge connections. Four dial ranges: 2 15/20/60 min, are available, with 80 to 120 scale divisions. Silver contacts carry 30 amps. at 110 volts a.c. Motor is Telechron. Choice of three cases is offered: "No. 18" (5½"x8" x5" deep), "No. 19" (same but with gasketed opening), "No. 22" flush-mounted.—*Automatic Temperature Control Co., 34 East Logan St., Philadelphia, Pa.*

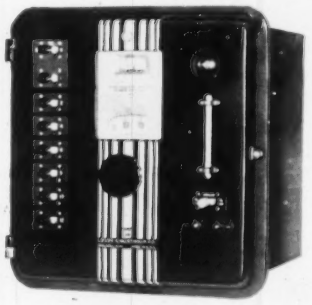
Extra-long-scale Flowmeters for Tests & Calibrations

For important engineering tests, and for calibrating either "positive" or "inferential" fluid meters of ordinary grades, a new series of "Rotameters" is announced, having precision-bore tubes approx. 24" long, with 60-cm. graduated scales. Intrinsic (mechanical) precision is 0.0005% and guaranteed limit of error (in flow-rate indication) is 0.5% throughout a 30:1 range. End fittings regularly supplied are "panel attachment" type as illustrated at left (⅓ actual size). Right-hand illustration (⅓ actual size) shows etched millimeter graduations.—*Fischer & Porter Co., 114 W. Penn St., Germantown, Philadelphia, Pa.*



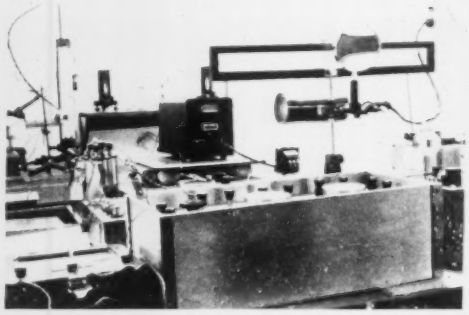
Multiple-thermocouple Indicating Potentiometers

Space for any number of toggle-switches, for connecting any one of a number of couples to the measuring circuit, is provided in new switchboard models of temperature indicating potentiometer. Measuring circuit is hand-standardized, but



automatic reference-junction compensation, eliminating uncertainties due to circuit-resistance variables. Scale is practically uniform and equally accurate throughout, and can be calibrated for single- or double-range, latter for use with similar or different couples. Built-in terminals, check key and mercury thermometer can be included for hooking with a portable indicator. Case mounts flush in panel, but can be equipped with hangers for surface mounting. Galvanometer is replaceable. Only maintenance is occasional dry-cell replacement; warning that dry-cell must be renewed is given when a red disk appears above indicator scale. Separate selector switches can be used external to indicator, if desired, or space for additional self-contained toggle-type switches may be obtained by assembling indicator (with case removed) in a cabinet similar to that of maker's "Micromax" strip-chart recorder.—*Leeds & Northrup Co., 4955 Stenton Ave., Philadelphia, Pa.*

EPPLEY THERMOPILES



A view of some of the apparatus used for calibrating thermopiles at the Eppley Laboratory, Inc.

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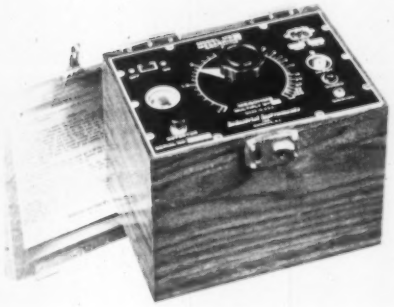
eakage Resistance Tester

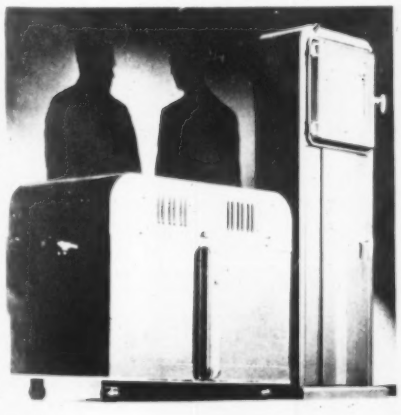
"Series MB Megabridge" is claimed "the most rapid device for routine in- tests which still retains the inher- curacy of the Wheatstone Bridge." For



production test routine, pointer knob is set to insulation value limit, device to be tested connected, and "detector" button is pressed. If insulation value is below standard, null indicator signals this condition. For measuring resistances, pointer is turned until opening of null indicator remains centered with "detector" button depressed. Electrically, "Megabridge" is an adaptation of Wheatstone bridge, utilizing an electronic null indicator instead of a galvanometer. Operating from a-c power line, it has a self-contained d-c supply for bridge circuit and electron-ray tube. Calibration is said to be unaffected by fluctuations of line voltage or tube variations. For rapid testing of capacitors and high-capacity cables, instrument is arranged to charge capacitor automatically when connected to test terminals. High-potential terminal assembly is so shielded, it is said, that any leakage over surface of terminal insulation does not affect calibration. A third terminal is provided for use in measurements which require external guarding. Instrument is housed in a walnut cabinet, 8" x 7" x 5¾", weighs 10½ lbs. Accuracy: "Within 10% from 1 to 10 on scale and as close as readable for remainder of range." Eight models are available, four for 50-60-cycle 115-volt supplies and four for 25-60-cycle 115-230-volt supplies, megohm ranges being 0.1 to 100, 1 to 1000, 10 to 10,000 and 100 to 100,000. *Industrial Instruments Inc., 162 W. 23rd St., New York City.*

Recording Calorimeter

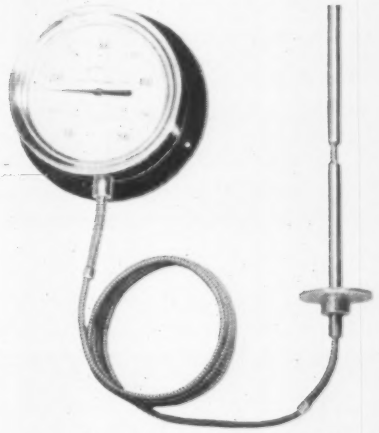
Completely redesigned, new Cutler-Hammer Calorimeter consists of a tank unit which continuously determines calorific value of gas and an instrument unit which records this value in terms of B.t.u.'s on a 30-day chart. According to maker's gas engineers, improvements in tank unit result in increased speed and accuracy of response because gas, through better "purging," reaches combustion chamber more quickly. Longer service is claimed, all under-water parts being of brass; idler gears have been eliminated and wearing parts reduced 10%.



oilless bearings are used on all slow-moving parts, in-built water treatment prevents biological growths. Makers also claim design and construction refinements for recording unit: new suppressed-zero chart which enlarges variations; eye-level visibility indications and permanent records; addition of a metal plate behind chart for making notes; synchronous motor chart drive; entire mechanism swinging out for easy inspection. *Cutler-Hammer, Inc., 126 North 12th St., Milwaukee, Wisconsin.*

Dial-indicating Thermometers

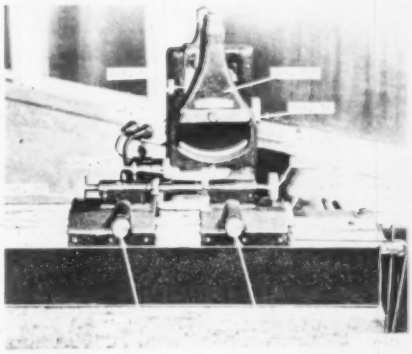
To maker's line of industrial electrical instruments is now added a line of dial-indicating thermometers with 6" dial for direct



mercury, gas-filled and vapor-pressure types, in remote-bulb and bulb-in-line types, with bottom-connected or back-connected stems. *Wheelco Instruments Co., 1939-51 S. Halsted St., Chicago, Ill.*

Thread Lead Tester

New Sheffield Lead Testing Machine is for comparing the lead interval of screw and worm threads against a precision block setting. Visual gage head, incorporating a



frictionless reed pivot with reed mechanism, is mounted on a bracket by four horizontal metal reeds to allow contact point to be lowered into and raised out of the screw thread being lead-tested. Work-carrying centers ride on pre-assembled ways and are locked together by turning knurled knob 14. Precision gage blocks should then be placed between contact rods on slide 37 and on base 38, so that right end of threaded portion is under contact point 29 in gazing head 30. To secure approx. vertical position, raise or lower bracket by means of hand knob 34 and lock in place with knobs 7. By means of hand knob 19 gazing head is lowered into thread. By turning piece to be gazed, shadow can be brought to zero on scale. Gazing head is then raised out of thread by knob 19. Remove blocks of proper size to allow slide to move to right through predetermined distance. Gage head can then be lowered into thread at this new point and accuracy of the lead read directly on scale. *Sheffield Gage Corp., Dayton, Ohio.*

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Industrial Instruments Course at the Charleston (W. Va.) Evening Trade School

By C. B. COCHRAN

Head of Instrument Dep't, Westvaco Chlorine Products Corp., South Charleston, W. Va.

IN recent years Industry, as a whole, has become more and more instrument-minded. Modern manufacturing plants today employ hundreds of industrial instruments as aids to improving quality of product, reducing waste and cutting labor costs. An entire industry now specializes in the manufacture of measuring and controlling devices. Several thousand types of instruments are manufactured by American companies. Nearly every day a new type or a refinement of some older type is introduced, and every day we are becoming more and more aware of the importance of these instruments. In order to insure their satisfactory performance, adequate provision must be made for their proper selection, installation and maintenance.

Until recent years, plant instruments were usually serviced by workmen as a side line to some other occupation. The results obtained from this plan, in most cases, did not do justice to the intended performance of the instruments involved.

The development of many new and more complex industrial instruments, especially in the field of automatic control, has altogether changed the type of men needed for instrument work. It is generally agreed today that an instrument department, the size of which depends upon the number of instruments being used in the particular plant, is necessary for proper installation and maintenance if the capital investment in instrumentation is to yield the anticipated returns. This instrument department is usually charged with the selection, the proper installation, and the satisfactory maintenance of all instruments which are in use in the plant. Facilities should be provided for minor repairs and for calibration and testing if the expected results are to be realized. Records which show the complete history of all instruments in use are often kept as a check on performance and as an aid in future purchases. Chart changing and filing and the compilation of data derived from these charts, for use by the Accounting Department, may also be taken care of by the instrument department. In many larger plants, the instrument department also designs and makes orifice plates for flow measurement, designs and fabricates special instruments, and, in general, works hand in hand with the production department to the end that productive efficiency may be increased to the maximum.

Most of the large instrument companies employ competent service engineers, who are available to service their equipment, so that it is only necessary to call the local agent when the occasion arises. However, when a plant uses a large variety of different makes of instruments (and this is usually the case in plants *not* located near a large city!) considerable loss of time and great expense would result from the lack of properly trained instrument men as part of the plant personnel.

The importance of employing properly trained instrument mechanics has been emphasized in recent *Instruments* articles:

"Selecting and Training Plant Instrument Men," G. P. Bosomworth, *Instruments*, November, 1935;

"Training Instrument Men Where Instruments Are Made," R. C. Keenan, *Instruments*, April, 1936;

"Organizing Plant Instrument Services," Alfred G. Moon, *Instruments*, December, 1936;

"Training Your Own Instrument Men," Alfred G. Moon, *Instruments*, January, 1937.

These articles all point out that the man or men working with industrial instruments, should thoroughly understand the theory underlying the instruments which he repairs as well as the process on which they are used. In other words, instruments are no longer considered "auxiliary gadgets" but are definitely an integral part of today's gigantic, precise, high-geared production set-up, and require a well-trained, intelligent man to keep in constant touch with their operation.

Since this is a relatively new field, the demand for trained instrument men far surpasses the supply. It is practically impossible today to find suitably trained men who are available for employment. Thus arises the need for a medium of training that will assure a reliable source of instrument men.

Most leading instrument manufacturers, realizing the importance of properly trained men for the servicing of their equipment, have established training facilities, not only for their own personnel, but also for users of their equipment; also many of the larger industrial plants, which already have well-organized instrument departments, have set up apprenticeship courses for their own personnel, which have proved successful. A comprehensive training program with instruction given on company time is, of course, out of the question for smaller plants, and it is virtually impossible to send men to training schools maintained by the instrument manufacturer. This fact presents a serious handicap to the small plant, requiring trained men for the maintenance of their instruments.

Since there are a large number of industrial plants located in the Kanawha Valley, centered around Charleston, West Virginia, and since most of these plants maintain instrument departments, varying in size from one to as many as fifty men, it was thought that there would be a demand for a training course whereby these men could add to their present knowledge and keep up to date on the newer types of instruments.

Consequently, it was decided to include a course in Industrial Instruments in the curriculum of the Charleston Evening Trade School. This trade school was made possible by the provisions of the Smith-Hughes Act of 1917, which provides for the "promotion of vocational education," and the George-Deen Act, of 1936, providing for "further development of vocational education." Under these acts, the Federal Government agrees to make a substantial financial contribution to the support of vocational education.

The Charleston Evening Trade School is open to workers over sixteen years of age lawfully employed in trade and industrial occupations or who have been so employed and are temporarily unemployed. The classes are conducted in the evening when workers are able to attend and the instruction provided is supplemental to their daily employment. Thus the workers eligible to attend the class in Industrial Instrumentation must be men engaged in the repair, installation, and maintenance of general industrial meters.

Instructors in this program each hold a trade and industrial certificate issued by the Department of Education of the State of West Virginia. This certificate is issued to men who have trade or industrial experience and show a liking for teaching. Supervision of these instructors is provided by the Kanawha County Board of Education in cooperation with the State Department of Education.

Salaries of the teachers are paid by the County Board of Education, which is reimbursed by the State and Federal Governments. A small tuition is charged each student to provide the county's share of the cost. This tuition for the entire term is low and is considered a profitable investment by the men seeking instruction.

course in Instrumentation soon attracted widespread attention and during the registration period forty-four men signed up for instruction, all of whom are at present actively employed in instrument work. The actual mechanics of the course itself necessitated a certain amount of constructive planning, due to the varied types of men that would participate in the class and its programs. Evening classes automatically retard our flexibility in this case as some of the men work on shifts and are unable to attend regularly. The previous education of the group is also greatly varied, ranging from those who have stopped in their formal education as early as the ninth grade to those who have enjoyed two or more years in various universities and colleges. There are only a few of the latter.

It was realized at the outset that the course to be given could only form a background for future application and development, but nevertheless it had to offer practical and tangible information. The course must also be broad enough to cover most of the types of instruments used in the various plants represented by our students, otherwise our time would be spent to no avail. Another extremely important point dealt with the problem of how much time was to be allotted to each general type of instrument and its underlying theory. This brought us back to the problem presented by the varied degrees of training possessed by our students. Time allotment would depend solely upon how fast the *class* as a whole could assimilate and digest the subject material. Twenty-four weeks is a relatively short time in which to present any type of course in instrumentation, so we had to arrange our time so that the most difficult subjects would receive the maximum time allowed under the circumstances. We had to keep in mind the fact that we would possibly tend to slight some of the simpler but nevertheless fundamental subjects. Consequently, it was necessary to "feel" our way, so to speak, through some of our first lectures just to see how our students would grasp our presentation. In this manner, we soon were able to apply the proper amount of time to the various subjects that indicated a need for more intensive work. Since all of the men had had some experience with instruments, it was less necessary to dwell on the use and importance of these instruments than it was to explain in detail the underlying theories.

A general outline was presented in which it was planned to offer information that would deal primarily with the underlying factors or theory behind the various types of instruments. Otherwise, it was decided, we would still have a mechanic who would not be able to solve problems as they presented themselves, and in many instances, would not be able to determine whether an instrument was performing as it should. A man not realizing how a change in temperature affects the process, for instance, could not intelligently service the instruments.

A class of forty-four men of varied degrees of training is too unwieldly to be handled by one instructor during one period. Consequently, the class was divided into two groups and Mr. E. A. Bryant, an instrument engineer in one of the local plants, and the writer were chosen as instructors. The classes are held on Tuesday and Thursday evenings from seven to nine-thirty. In order to facilitate the handling of the class and to afford the students a psychological variation, each period was divided into two separate sessions. The first session ends at 8:10 p.m., followed by a ten-minute intermission. The second session follows from 8:20 to 9:30 p.m., with the two groups alternating. For example, Mr. Bryant will lecture to Group 1 and the writer to Group 2, during the first session. At the second session each instructor repeats his lecture, but to different groups. This plan worked out satisfactorily, and we believe that this is one of the reasons why our attendance was maintained in such a gratifying manner.

It had been expected that we would have a 50% mortality rate in attendance. This figure was based on previous experience with classes at the Evening Trade School. However, we were pleasantly surprised, when at the end of twelve weeks—the first half of the course—our enrollment showed a decrease of slightly more than 25%. This was encouraging since we felt that our students were not only absorbing the subject material, but also realized the necessity for such a course, i.e., the need for properly trained instrument men. This attitude is an excellent thing for industry and promises further development in the progress of instrumentation in the Kanawha Valley.

We were, in a way, handicapped by the lack of a textbook covering the subjects, but to no great extent. Many of the instrument manufacturers have supplied us with bulletins and pamphlets for each member of the class, and these publications, which describe in detail various types of instruments, have been used in lieu of a regular text. These companies have gone still further in their aid and cooperation. At the end of the discussion on each general type of instrument, a sales and service engineer from one of the instrument companies has discussed the theory of that company's instruments and their application to the various problems involved. These lectures last the full 2½-hour period, and are given to both sections of the class at one time. Subjects covered to date by these lectures are: "Pressure and Temperature Recorders and Indicators"; "Liquid-in-Glass Thermometers and Hydrometers" and "Air-operated Control Systems." Lectures scheduled in the near future include "Flow Measurement by Orifice Meters," "Millivoltmeter and Potentiometer Pyrometers" and "Rotameters." These lectures serve as a summary of the subject just completed and provoke discussion that not only is enlightening to the students but also indicates to the instructors the extent that the students have progressed and their reaction to the entire subject. Thus, we can be guided in future subjects as to just what points should be stressed and how to deal with the student as an individual. The discussions with these engineers are an extremely important factor in the successful training of the students. It further shows that the instrument-makers are not to be disregarded in planning for future and more complicated courses for potential instrument men.

The instrument manufacturers' literature, mentioned above, proved to be a great aid in the presentation of our subjects. All of the bulletins and pamphlets contain diagrams, explaining the internal construction of the instruments under discussion. Sectional views of instruments afford the student an opportunity to grasp its fundamentals far more clearly than any means to which we have access at the present. We have no laboratory facilities at this time and it can be easily understood that this handicap hampers both presentation and absorption of the points presented. For this reason, we depend a great deal upon illustrated bulletins.

The underlying theme of the course stresses the necessity for well-trained instrument men, who will be able to take hold of and service the utmost efficiency, any type of instrument on any process. Throughout the course, students were reminded that repair work done on a trial-and-error basis usually ends as an error. It was also pointed out that the instrument mechanic should become thoroughly familiar with the various processes on which his instruments are used. It often happens that a trouble call is received by the instrument department when some other part of the process is really responsible for the trouble, and a great deal of time and money can be saved by the man that can properly and quickly diagnose the trouble.

The ideal course in Instrumentation should provide its students with a laboratory, in which they will be able to actually work on each instrument as they study. Especially is this true in the case of a school whose object is to train new men, strangers in the field of Instrumentation, who have never worked with instruments. The ideal course should also have two phases—one of theory and one of actual practice. This procedure would assure each student of receiving the utmost that the course has to offer.

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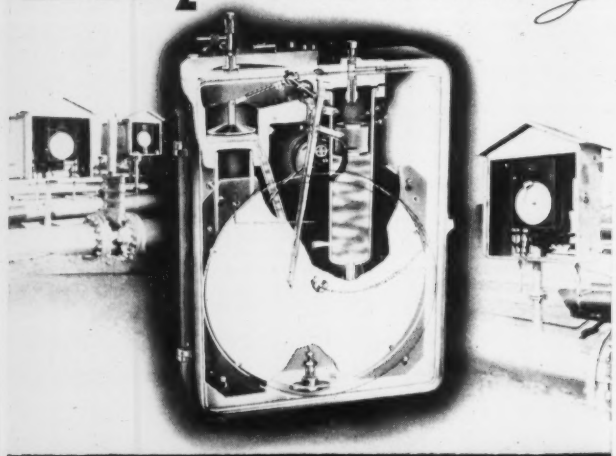

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engineers, and in my opinion it will be but a short before the "ideal course" will be offered to those who to further participate in the development of instrumenta

The following outline will indicate in a general way subject material to be covered during the twenty-four w Each set of topics is presented to each student group; instructor presents subjects listed under column "A," another instructor presents those under column "B." In way, each instructor presents his lecture twice in one ning. This plan enables each instructor to intensify efforts and cover his subject more thoroughly than if covered subjects included in both columns. Furthermor enables the student to grasp the subjects in a more cise manner. The fact that the subjects are so segreg facilitates assimilation by the student.

A	B
I. Temperature Measurement	*I. Pressure Measurement*
1. Theory of heat	1. Liquid column gages
2. Absolute temperature	2. Piston gages
3. Temperature scales	3. Diaphragm gages
4. Thermometry	4. Bourdon tube gages
a. Liquid-in-glass thermometers	5. Metallic bellows
b. Pressure-type thermometer systems	6. Differential gages
(1) Liquid-filled systems	7. Calibration
(2) Vapor pressure systems	8. Selection of pressure instruments
(3) Gas-filled systems	9. Installation and maintenance
c. Pyrometric cones	*II. Electrical Temperature Measurement*
d. Optical pyrometers	1. Fundamentals of electricity
e. Radiation pyrometers	2. Thermoelectric pyrometers
5. Calibration	a. Thermo couples
6. Selection of temperature instruments	b. Millivoltmeters
7. Installation and maintenance	c. Potentiometers
	3. Resistance thermometers
II. Automatic Control	a. Wheatstone bridges
1. Need for control	4. Calibration
2. General principles	5. Installation and maintenance
3. Types of controllers	*III. Photoelectric Cells*
4. Factors favoring controllability	1. Principle
5. Controlled valves	2. Application
6. Selection of controllers	3. Maintenance
7. Installation and maintenance	*IV. Thermal Conductivity*
III. Flow Measurement	1. Principle
1. Related physics	2. Application
a. Hydraulics	*V. Gas Analyzers*
b. Gas laws	1. Details of construction
c. Viscosity	2. Calibration
2. Discussion of primary elements	3. Installation and maintenance
a. Weirs	*VI. Telemetering*
b. Pitot tubes	1. Selsyns
c. Venturi tubes	a. Principle
d. Flow nozzles	b. Application
e. Orifices	c. Maintenance
3. Orifice design	2. Electrical flow meters
4. Mechanical flow meters	a. Details of construction
a. Details of construction	b. Calibration
b. Calibration	c. Installation and maintenance
c. Installation and maintenance	

Reference works, other than the instrument manufacturers

1. Behar, "Fundamentals of Instrumentation"

1. Behar, "Fundamentals of Instrumentation"
2. Duff, "Physics"
3. Weld & Palmer, "Textbook of Modern Physics"
4. Wood & Cork, "Pyrometry"
5. Croft, "Power Plant Practice"; "Practical Heat"
6. Moyer, "Power Plant Testing"
7. Fielding, "Photo-electric and Selenium Cells"
8. Campbell & Ritchie, "Photoelectric Cells"
9. Laws, "Electrical Measurements"
10. King, "Handbook of Hydraulics"
11. Perry, "Chemical Engineers Handbook"
12. Westcott, "Measurement of Gas and Liquids By Orifice Meter
13. American Society of Mechanical Engineers, "Fluid Meters Their Theory and Application"
14. American Gas Association, "Gas Measurement Committee Report No. 2"
15. Foxboro Co, "Principles and Practice of Flow Meter Engineering"
16. Brown Instrument Co, "Flow Meter Engineering Handbook"
17. MacLean, "The Orifice Meter"
18. Spink, "Handbook of Steam Flow Measurement"
19. American Society of Mechanical Engineers, "Power Test Code Instruments and Apparatus," Part 1, Part 2, and Part 3
20. American Society of Mechanical Engineers, *Transactions*, November, 1938
21. Perazich, Schimmel, and Rosenberg (WPA National Research Project), "Industrial Instruments and Changing Technology"
22. *Instruments* Magazine

A New Method of Measuring Strain Distribution—Brittle Coatings

By A. V. de FOREST

Massachusetts Institute of Technology

DURING the past year development work has been carried out in the Mechanical Engineering Department of the Massachusetts Institute of Technology by Mr. Trevor Ellis under the direction of Professors A. V. de Forest and E. S. Taylor, on the use of brittle coatings for strain analysis of three-dimensional bodies. Since it usually is true that maximum strain concentrations—especially those inciting failure under fatigue conditions—occur on the surface, the new method opens possibilities of quickly and conveniently performing a qualitative strain analysis upon the most complicated shapes.

The general procedure is to coat the surface of an actual part, whose design is being analyzed, with a coating of uniform brittleness and load the part in a manner simulating use, so that the coating is caused to rupture first at points of high strain concentration and later (with higher loads) in areas of more general strain distribution. By measuring the loads at which these rupture patterns form, the strain concentration ratios can be computed as the inverse ratio of the loads required to form patterns on the respective areas. Actual values of strain can be computed by calibrating the brittleness of the coating under the conditions of test.

Suitable lacquers have been developed which will form uniformly brittle coatings within a thickness range of 0.001" to 0.01" after an overnight drying. A method of analysis has been developed which will indicate magnitude of maximum tension strains, utilizing the lacquer alone, to an accuracy of within 20% and the direction of these strains to a much higher order. The coating constitutes, in effect, a strain gage which not only pictures strain conditions but allows evaluation of concentrations with an effective gage length as small as 0.01".

The figures illustrate the application of the method to the determination of the strain distribution about a spotweld between two sheets under direct tension, and also when one sheet is rotated with respect to the other about the single spotweld. In the case of the tension specimen the cracks first formed within the spotweld and then at higher values of load spread to the surrounding metal. For the rotation example the cracks first formed around the edge of the spotweld and then spread in towards the center of the spot and out into the adjacent sheet. In this case the cracks are showing the resolved maximum tension of the shear due to torsion.

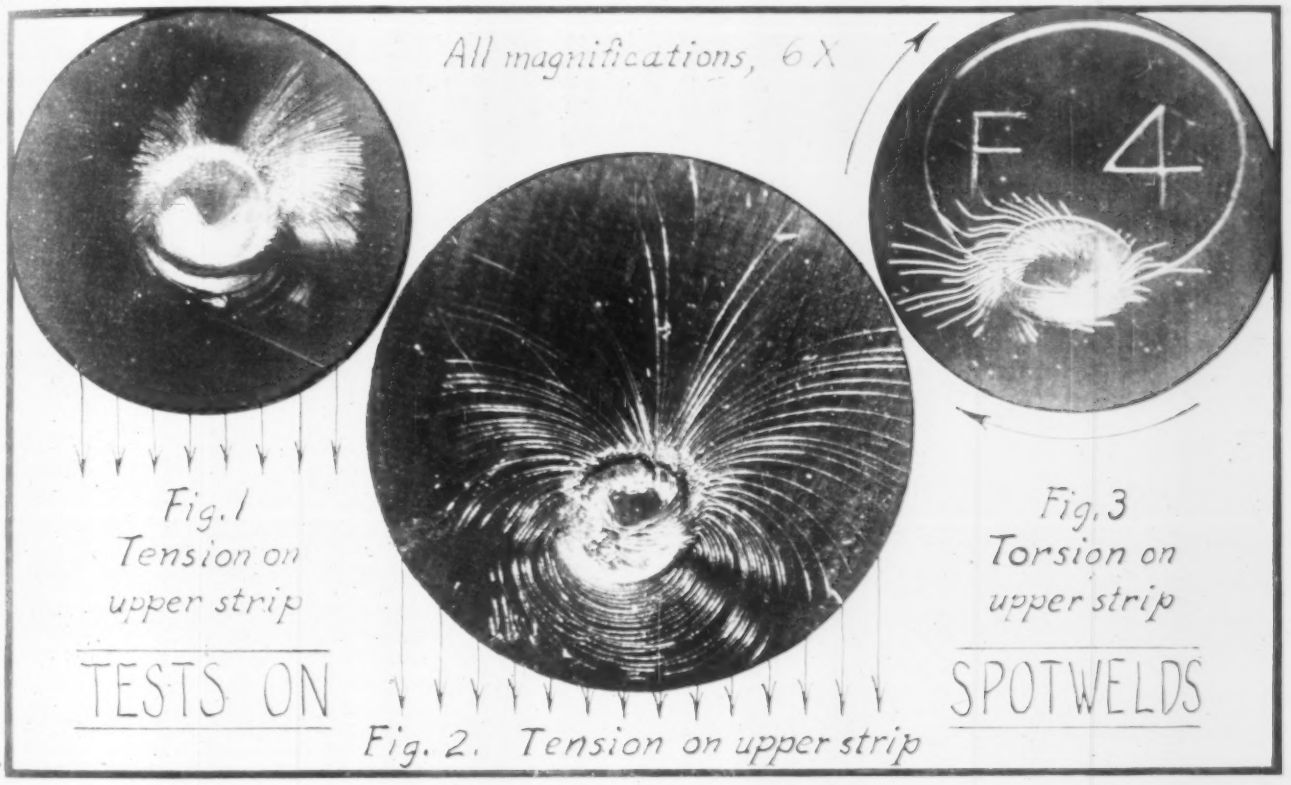

Fig. 2. Tension on upper strip

In each case the crack rupture lines are always normal to the direction of maximum tension at every point and well illustrate a valuable feature of the general picture provided by the coating, in that they graphically show in what direction a normal point by point strain gage should be placed in order to record the maximum deflection. Incidentally, it is worth noting the small area within which these fairly complex analyses are made, in that the actual diameter of the spotweld is $\frac{1}{8}$".

The system may be applied to many problems of stress analysis involving static or impact loads, on either a large or small scale. This method of investigation will shortly be available to industry.

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Illinois' Oil Inspection Trailer

By C. S. HOLMBERG

Supervisor Motor Fuel Tax and Oil Inspection Division, Illinois Dept. of Finance

A MOBILE laboratory being put into servi to test petroleum produc sold at Illinois filling station and to serve as an exhib acquainting citizens wi their State Government's e forts to safeguard the against sub-standard pro ucts. The accompanying p tographs show the unit designed by A. L. Newm of the Precision Scient fic C Chicago, working with writer.

Top. Outside view of the first unit. *Left circle.* Seen through a window: outlet for 110-volt procured from outside; Saybolt chomometer; leveling mechanism of distillation apparatus. *Right circle.* Taking samples. *Center.* Looking into laboratory: (l. to r.) ice chest, Monel sink, closed-cup flash tester, compressed-gas tan'ks, distillation apparatus. *Lower left.* Seen through window: chromometer eyepiece, Monel sink with hand pump for water pressure (indicated by gage). *Lower right.* Seen through window: "Precision Ful-Kontrol" 4-unit distillation apparatus.

Relations Involved in Metering Rate-of-flow

By ED S. SMITH, JR.
Hydraulic Engineer, C. J. Tagliabue Mfg. Co., Brooklyn, N. Y.

While this subject generally has been treated conventionally, i. e., from the aspect of conservation of energy, the present notes cover a number of different approaches. Many of us are not satisfied with a single statement of material which we use, but need to have a number of different aspects on a subject to have confidence in our judgment when handling actual calculations. In a sense, the following group of sections may be thought of as constituting the basic triangulation system for the subject of flow metering.

First is Section 1, a slightly modified development of the original treatment by Prandtl and Tietjens, that shows how the pressure-volume path followed by the fluid affects the expansion factor and determines the law of flow, be the fluid a liquid or a gas. This is followed by Section 2 containing the conventional development for gases, based on the law of conservation of energy, which method gives an insight into the mechanism of the energy transformations involved. Next is Section 3 upon empirical coefficients and expansion factors and their graphical correlation with the Reynolds number R and the acoustic ratio S. After this comes Section 4: a brief study of fluid reaction forces and their implications, a useful analytical shortcut for a few important cases. Concluding Section 5 contains a presentation of Borda's relation, for changes of momentum at a change of section, which clears up some additional points upon losses and expansion factors.

1. Prandtl-Tietjens Relation between Pressure and Velocity.

The fluid is accelerated through the drop in pressure along a nozzle, taking this as the differential producer. Since force equals mass times acceleration, with

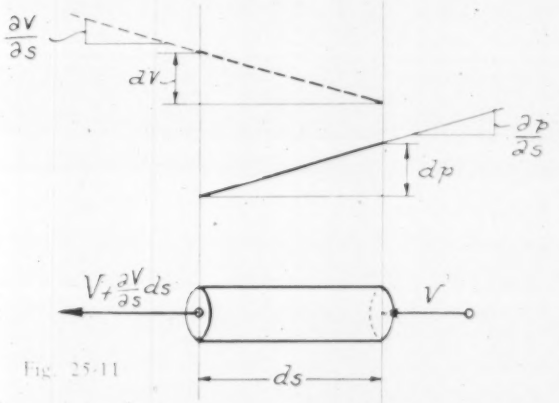

Fig. 25-11

a unit area streamline, the force accelerating a fluid particle ds long, and hence having ds volume as in Fig. 25-11, is

$$w\, ds \frac{dV}{dt} = -\frac{\partial p}{\partial s} ds \quad \ldots \quad (1)$$

where w is the density, V is the velocity, p is pressure, ds is the mass and dV/dt is the acceleration. $\frac{\partial p}{\partial s} ds$ is the difference in pressure on the two ends of the particle. We need to eliminate the time and distance factors from the equation so that our result will be expressed only in density, pressures and velocities.

The longitudinal change in velocity between the two ends of the particle along the streamline is

$$dV = \frac{\partial V}{\partial s} ds \quad \ldots \quad (2)$$

where the ratio represents the rate of variation of velocity with distance. Then,

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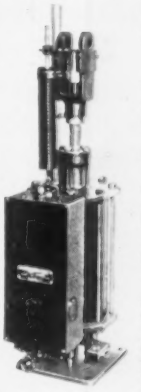

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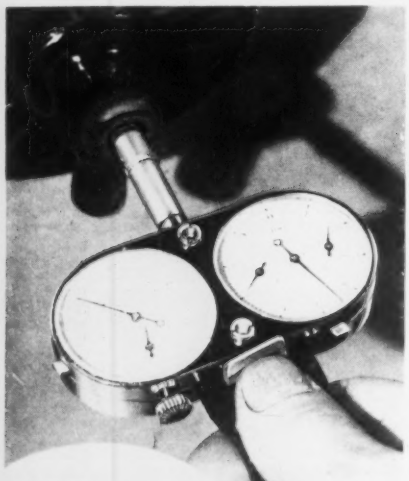

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to obtain the acceleration, divide both sides by dt, and since $V = \frac{ds}{dt}$,

from (2) and (3)

$$\frac{dV}{dt} = \frac{\partial V}{\partial s}\frac{ds}{dt} = V\frac{\partial V}{\partial s} \quad (4)$$

We next eliminate the time factor by substituting (4) in (1),

$$w\,ds\,V\frac{\partial V}{\partial s} = -\frac{\partial p}{\partial s}\,ds \quad (5)$$

and, by integrating along the streamline,

$$\int_1^2 V\,dV = \int_1^2 -\frac{1}{w}\,dp \quad (6)$$

we eliminate the distance factor.

With a liquid, the density remains constant during a metering pressure differential, so that, integrating (6),

$$\frac{V_2^2 - V_1^2}{2} = \frac{p_1 - p_2}{w} \quad (7)$$

Thus, for a nozzle with negligible approach velocity, from the standpoint of kinetic energy, the metering relation is that the mass-rate is

$$M = C a_2 \sqrt{2(p_1 - p_2)\,w_1} \quad (8)$$

With a gas expanding adiabatically (see Fig. 25-12), *i. e.*, without losses or

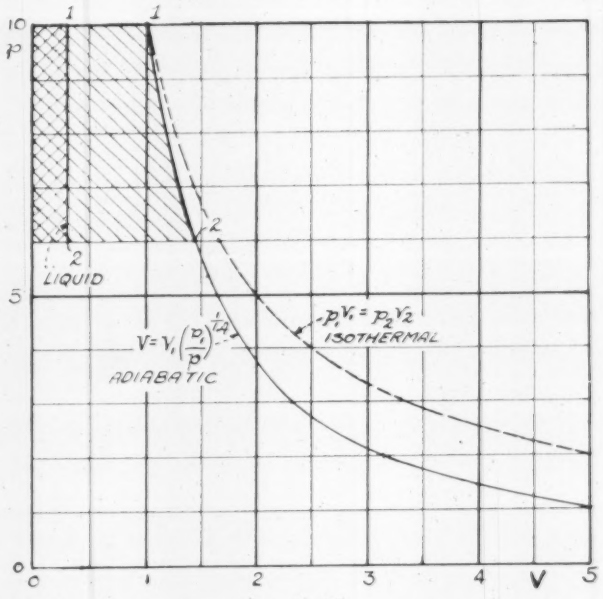

Fig. 25-12

heat input (the usual situation), the gas cools slightly as it expands, so that

$$w = w_1\,(p\ p_1)^{1/k} \quad (9)$$

where k is the effective specific heat ratio, *i. e.*, exponent of isentropic expansion. Substituting (9) in (6) and integrating

$$\int_1^2 V\,dV = \frac{p_1^{1/k}}{w_1}\int_1^2 \frac{1}{p^{1/k}}\,dp \quad (10)$$

and integrating

$$\frac{V_2^2 - V_1^2}{2} = \frac{p_1^{1/k}\,k}{w_1\,k-1}\left(p_1^{-k+1/k} - p_2^{-k+1/k}\right) \quad (11)$$

which becomes

$$\frac{k}{k-1}\frac{p_1}{w_1}\left[1 - (p_2\ p_1)^{k-1/k}\right] \quad (12)$$

Assuming negligible approach velocity as before, the flow equation is

$$M = CY a_2 \sqrt{2(p_1 - p_2)\,w_1} \quad (13)$$

where the net expansion factor Y, in this case also the theoretical, is

$$Y = \left[\frac{k}{k-1}\left(\frac{p_2}{p_1}\right)^{\frac{2}{k}}\left(\frac{1 - (p_2\ p_1)^{k-1/k}}{1 - p_2\ p_1}\right)\right]^{1/2} \quad (14)$$

2. Conservation of Energy: Potential and Kinetic Energy

To pump a unit mass (e. g. 1 pound) of liquid from a low to a higher pressure requires work,

$$E = \frac{1}{w}(p_2 - p_1) \quad \text{(ft. pdl.) hr.} \qquad (15)$$

This is the difference in potential energy which is, by the law of conservation of energy, converted into kinetic energy in a nozzle giving parallel flow with no losses. Neglecting the approach velocity as before,

$$\frac{V^2}{2} = \frac{1}{w}(p_1 - p_2) \qquad (16)$$

which is seen to agree with equation (7) of the foregoing section.

With a gaseous fluid, the expansion path is usually the adiabatic but it may be helpful first to consider several other paths in reaching an appreciation of

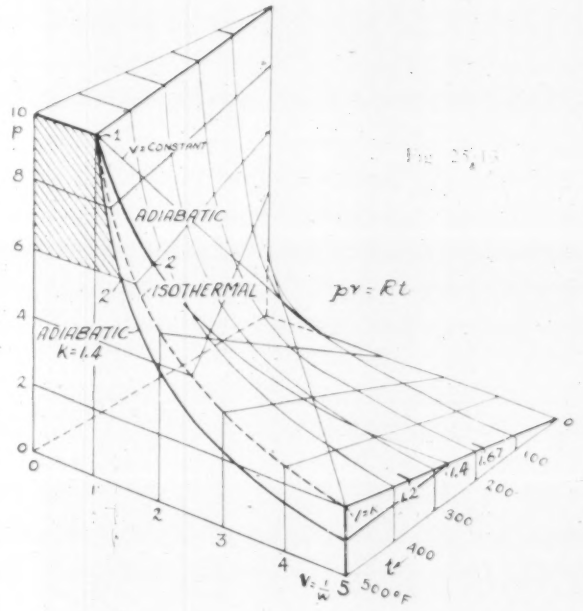

Fig. 25-13

the meaning of the terms used for adiabatic flow. The constant volume path for a liquid has just been considered, there being no appreciable change of the internal energy with change of pressure. However, with a gas "expanding" along a constant-volume path, heat must be removed to decrease the temperature. The internal energy change is

$$\Delta I = c_v \frac{1}{wJR}(p_2 - p_1) \qquad (17)$$

as is apparent from Fig. 25-13, R being the gas constant, i. e. the number of ft. pdls. required to increase the temperature of one pound of gas 1° F. The external energy change is $(1 - w)(p_2 - p_1)$ and the heat change is, again from the graph, $c_v(1 - wc_v/R)(p_2 - p_1)$, so that the net change of potential energy is as before in (7) and (16).

For a "constant pressure expansion" in which there is an increase of volume due to an increase of temperature, the change of internal energy is $c_v(p_2 - R)(1 - wc_v/R - 1 - wc_v)$, the change of external energy is $p_1(1 - wc_v/R - 1 - wc_v)$ and the heat input is $[(c_v - R) + 1]p_1(1 - wc_v/R - 1 - wc_v)$ and the net change of potential energy is zero, which shows that there would be no flow even if one did not already know that this must be so.

A constant temperature expansion may be achieved in either of two ways: letting the gas expand adiabatically and then reconverting all of the kinetic energy into heat energy or by adding just enough heat to overcome the adiabatic expansion cooling. Since the first case tells its own story as regards the final velocity, we will consider here only the second case. In this case, there is no change of internal energy. Since for this case, the volumes and pressures are inversely related, there is no external energy change. The heat input necessary to overcome the natural cooling of expansion of $p_1v_1 \log_e (p_2 - p_1) \log_e (p_2 - p_1)$, which constitutes the entire change of potential energy and equals $V^2/2$.

In an adiabatic expansion, no heat is added and no losses occur. The change of internal energy is $[1 - (k - 1)](p_1/wc_v - p_2/wc_v)$ and in external energy is

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$p_1 w_1 = p_2/w_2$ so that the change in potential energy $[k/(k-1)](p_2 w_2 - p_1 w_1)$ is $[1 - (p_2/p_1)^{(k-1)/k}]$ is $V^2/2$, (reversible adiabatic = isentropic).

As far as accelerating the fluid goes, the pv path tells the story, as was brought out in Section 1. Fig. 25-13 shows that the trace of the expansion path on the pv plane is only one part of the story of the interchange of energy from heat to velocity. In many explanations of the specific heats at constant volume and constant pressure, the statement occurs that no change of energy other than internal, occurs unless the specific volume changes. Of course, when the fluid itself is flowing from one pressure to a lower, this is not so, as was brought out earlier in this Section.

Referring again to Fig. 25-13, the adiabatic flow path is seen to vary for gases of different specific heat ratios, the highest ratio being 1.67 for monatomic gases, 1.4 for diatomic gases (air e. g.), and on down to 1.25 for gases having 6 atoms per molecule, 1.2 being shown on this graph. The reason for the variation may be grasped by considering that when the molecules collide they acquire different amounts of total kinetic energy, upon an increase of temperature, depending upon whether the molecules are spherical or spin upon collision. The monatomic molecules merely exchange translational energy upon collision, while a molecule of a diatomic gas has (on the average) rotational energy involved when a spin is set up about an axis transverse to that between the centers of the atoms. A triatomic gas molecule can spin about any axis upon a collision; and the molecules of gases having higher numbers of atoms per molecule merely have slightly differing moments of inertia about their different axes and a slightly higher net average moment of inertia for purposes of energy computation. This situation is reflected in the following table of specific heat ratios for the several atomic numbers listed as calculated by Nusselt. The specific heat ratio for steam is practically 1.3, as regards flow metering calculations.*

Atomic number	1	2	3	4	5	6
Specific heat ratio	1.67	1.40	1.27	1.28	1.28	1.25

In this table, the specific volume v is used instead of $1/w$, the inverse of the density.

* Note—This table differs from Table II, p. 38, Elements of Heat Power Engineering, Hoyt & Barnard, John Wiley & Sons, Inc., 1918 Ed. by having ΔExt. (additionally include the external work to flow.

A brief résumé of a few of the elementary gas laws may be convenient here for those having only occasional use for them.

$pv = Rt$ or $p = Rt\,w$ or $t = pv/R$

Total energy = sensible + external + kinetic

H = Int. + Ext. + $V^2/2$

Specific heats, remembering that

1 Btu = 778 ft.-lbs. force
= 778 × 32.174 ft.-pds. = 25,030 ft.-pds.

$R = pv$ t for 1 lb. of gas.
$w = 1$ $v = p/Rt$

$c_v = \dfrac{\Delta H}{w\,(t_2 - t_1)}$ no external work being done in raising temperature.

* See Keenan and Keyes steam tables for more accurate values.

	Δ Int.	=	Δ Ext.	+	Heat Input	=	Work done.
constant	Δ Int.		Δ Ext.		ΔH		Kinetic Energy Increase
volume (liquid)	0		$v_1(p_2 - p_1)$		0		$v_1(p_1 - p_2)$
volume (gas)	$c_v \dfrac{v_1}{R}(p_2 - p_1)$		$v_1(p_2 - p_1)$		$c_v \dfrac{v_1}{R}(p_2 - p_1)$		$v_1(p_1 - p_2)$
pressure (gas)	$c_v \dfrac{p_1}{R}(v_2 - v_1)$		$p_1(v_2 - v_1)$		$\left[\dfrac{c_v}{R} + 1\right] p_1(v_2 - v_1)$		0
temperature (gas)	0		0		$p_1 v_1 \log_e (p_2/p_1)$		$p_1 v_1 \log_e (p_2/p_1)$
adiabatic (gas)	$\dfrac{1}{k-1}(p_2 v_2 - p_1 v_1)$		$(p_2 v_2 - p_1 v_1)$		0		$\dfrac{k}{k-1} p_1 v_1 \left[1 - (p_2/p_1)^{\frac{k-1}{k}}\right]$

$$c_p = \frac{R}{25{,}030} \text{ and } k = c_p \div c_v \text{ specific heat ratio}$$

adiabatic expansion, the gas flows without addition or subtraction of and the temperature drop times c_p equals the volume increase times the of pressure which, in turn, equals the work done. The pressure drops the gas cools and expands, $t_2 - t_1 = (p_2 - p_1)^{(k-1)/k}$, the gas volumes are as $= p_2 v_2^k$ and $25{,}030\ \Delta \text{ Ext.} = (p_1 v_1 - p_2 v_2)\ (k-1)$ ft.-pdls. which go into accelerating the gas, $25{,}030\ \Delta \text{ Ext.} = R\ (t_1 - t_2)\ (k-1)$

$$= \frac{R t_1}{k-1} \left[1 - (p_2 \div p_1)^{(k-1)/k} \right]$$

$$= (p_1 \div w_1) \frac{k}{k-1} \left[1 - (p_2 \div p_1)^{(k-1)/k} \right]$$

$$= p_1 v_1 \frac{k}{k-1} \left[1 - (p_2 \div p_1)^{(k-1)/k} \right]$$

which is commonly used in developing the flow meter equations.

3. Graphical Correlation of Coefficients and Expansion Factors against the Reynolds Number and the Acoustic Ratio.

The coefficient C is dimensionless and consequently depends upon the dimensionless ratio Vd/ν involving the pertinent variables*: velocity V, diameter d and kinematic viscosity ν, according to the requirements of dimensional homogeneity. (This ratio Vd/ν is generally known as the Reynolds number.) Consequently, the values of the coefficient C experimentally obtained with one liquid may be plotted against the Reynolds number R on a C:R graph and used in predicting the value of coefficient for similar meters and for another liquid as long as R is known. Different sizes of pipes and meters are of sufficiently different relative roughness in practice to slightly affect the "shape," i. e. for larger pipes which are relatively smoother than small pipes, the coefficient of a nozzle may increase slightly and that of an orifice decrease slightly, the direction and amount of change in general being proportional to the slope of the coefficient on the C:R graph. This is a good reason for using differential producers having flat coefficients over the metering range whenever possible. The Reynolds number may be thought of appropriately as expressing the ratio of inertia to viscosity effects. A high Reynolds number indicates that the inertia effects, upon which the metering formula is based, preponderate so that the coefficient tends to flatten out there at the "theoretical" values of unity for well-shaped nozzles and $\pi/(\pi + 2) = 0.6110$ for orifices (assuming two-dimensional flow, the three-dimensional case with a circular orifice in an infinite thin plane being still too difficult for solution by exact methods).

For expansible fluids, i. e. gases and vapors, the same dimensional method would indicate that the expansion factors are related to the acoustic velocity ratio (the Mach number), i. e. the ratio of the velocity of the fluid at the inlet to the meter to the velocity of sound there. The following will show that there is some physical justification for such treatment.

As the pressure ratio drops, the velocity increases through the throat of a nozzle while, at the same time, the fluid density w_2 there drops. With negligible velocity of approach, the resultant mass-rate of flow reaches a maximum when $p_2/p_1 = [2/(k+1)]^{k/(k-1)}$ (= 0.53 closely for $k = 1.4$ for air, e. g.) from these factors. When this occurs, the acoustic velocity (that for sound) is reached at the throat. In Fig. 25-13, the paths are drawn in below the 0.5 pressure ratio, although actually they will not extend down quite so far with nozzles for the usual ratios of diameters.

The acoustic velocity is $V_a = \sqrt{k p_1 / w_1}$ and the inlet velocity is

$$V_1 = Q_1/a_1 = [C\Upsilon_1 / \sqrt{(m^2 - 1)}] \sqrt{2 \Delta p_1 / w_1}.$$

For a "flat" coefficient C, the acoustic velocity ratio is $V_1/V_a = K_1 \Upsilon \sqrt{S}$ where K_1 is a constant and $S = \Delta p_1 \div p_1 k$ = the acoustic ratio. However, for each value of the acoustic velocity ratio there is a corresponding value of the acoustic ratio, or $\Upsilon_1 = f_1(V_1/V_a) = f_2(\Upsilon_1^2 S) = f(S)$. To pass from the third to the fourth term of this equation merely requires that the Υ^2 factor be continuous and close enough to unity so as not to upset the fundamental correspondence involved. Thus, for an orifice or other differential producer, values of the net expansion factor Υ experimentally obtained on air ($k = 1.4$) e. g., may be plotted against the acoustic ratio S and used with any other gases ($k = 1.25$ to 1.67) for recommended diameter and pressure ratios without

*"Pigs is Pigs" is an ungrammatically rememberable way of stating the requirement that dimensions as well as numerics must equate.

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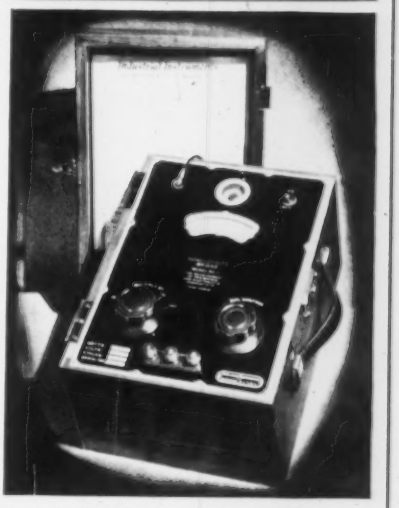

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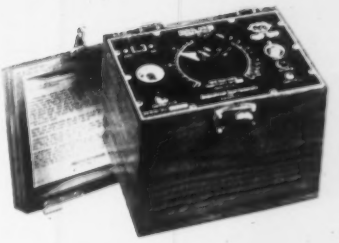

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errors greater than the experimental. The value of C used is that which would accompany negligible expansion effects and the same Reynolds number, as for a liquid. For a gas, C is assumed to vary with R as for a liquid and the "slack" is taken up by the net expansion factor Y. For the most accurate metering, a value of Y obtained with a "similar" (except for roughness) orifice will be satisfactory, although the coefficient C may require individual correction.

Possibly we should take space here to note several points which are not fundamental but of some practical importance:

(1) The use of the mass-length-time system of dimensions seems to be somewhat better than the force-length-time system for analytical purposes, at least in this fluid flow field. The main point is that the gravitational acceleration constant "g" does not appear with the mass system except when it actually has bearing on the physical situation. The fear that the relatively unfamiliar "poundal" may be a nuisance in the mass system has proved to be unfounded in the present writer's experience in which it has almost invariably been found that a simple manometric head replaces the term involving poundals while the fluid flow, when given as the mass-rate in pounds per second or per hour, e. g., is invariably clear and understood, since a pound of mass weighs a pound. It seems unfortunate that the misleading force system should be called the "Engineers' System."

(2) For flow in channels in which the shape is not fixed but depends upon the flow, as with free surfaces in weirs (or with impulse-plate meters), the shape of the stream profile depends upon the head H since this determines the horizontal distance to which the stream is thrown. This brings in an additional dimensionless ratio: Froude's number. For small heads with weirs, and for orifices discharging streams of liquid into a gas, the effects of surface tension s (and adhesion to the guiding surface) may become appreciable, in which case still another dimensionless ratio may be used in taking care of this effect upon the coefficient.

(3) For a comparison of the various differential producers, it is fairer to use the Reynolds number R_D based upon the pipe size than that R_d based upon the orifice size. However, the latter has earned general preference in practice since its use permits closer correlation of coefficients for venturis and nozzles than does R_D, the reason being that such devices commonly have fairly similar effective shapes as regards the most important working part, i. e. the throat. While the shape of the streamline profile of the vena contracta varies widely for the different ratios, the use of R_d is preferred by orifice advocates not only for its convenience but also because it gives a more favorable showing of flatness of orifice coefficients relative to those for other meters at low Reynolds numbers than does the other.

(4) The Reynolds number uses the velocity while the acoustic ratio uses the head. In any given problem, either velocity or head would be given but not both. This gap may be bridged in either direction by the use of the relation $V_i = \sqrt{2gH}$ where V_i is a fictitious velocity, with the result that computations may be made directly, i. e. without the use of approximations or graphical methods. This same artifice permits the use of a single graph for either purpose, e. g. the coefficients may be plotted against the Reynolds number and used with the head by utilizing simply skewed coordinates (on log-log paper).

(5) No present consideration will be given pulsating flow, helical flow, cavitation and other practical "installation" factors which make the accurate metering of fluids by head meters require unceasing interest and vigilance upon the part of the engineer in charge of their installation and maintenance.

4. Reaction of Nozzle Jets.

In Section 1, a particle of fluid was followed down its streamline and the relations between pressure and velocity found for both liquids and gases with a nozzle. In the present section, the relation between pressure and velocity is studied from the overall forces developed instead. It is used here only for liquid flow through a nozzle to bring out some phenomena not earlier mentioned in these notes. While it has elsewhere been used in dealing with expansible fluid flow through orifices, still this requires more space than is available in the present cursory treatment.

$$F = m\frac{dv}{dt} = M\,V = p\,a\,.$$

pdl. lb. ft. sec.^{2} lb. sec. ft. sec. pdl. ft.^{2} ft.^{2}

...us, starting with the general relation that force equals mass times accelera... we can shift one of the time divisors so that force equals mass per second ... the change in velocity, and this in turn is expressible in terms of force ... pressure times area. We are now concerned with the first, third and ... parts of the equation.

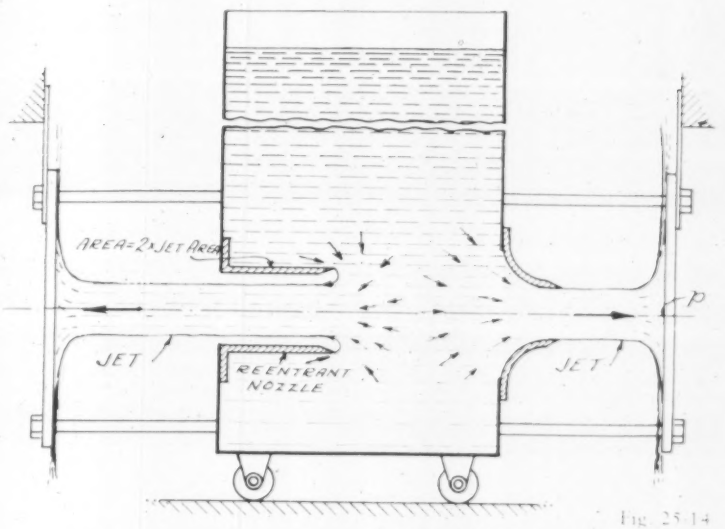

Fig. 25-14

Fig. 25-14 shows a jet from a reentrant nozzle having a parallel cylindrical wall (of cross-sectional area a_r) balanced by a jet of equal size and velocity from a simple streamlined nozzle ideally producing parallel flow, both jets being fed from a constant-head common reservoir so large as to render negligible any kinetic effects therein. Obviously the forces must be equal, so that from the fourth part of the equation, the jet areas must be equal since the pressures are equal. Also since the kinetic energy per pound of fluid is $V^2 \div 2$, and this equals the change in external energy $(1 \cdot ue)$ $(p_1 - p_2)$, then, equating forces,

$$a_r (p_1 - p_2) = MV = aueV^2 \div 2a (p_1 - p_2)$$

or, dividing by the differential pressure,

$$a_r = 2a$$

i. e., the area of the reentrant nozzle a_r is twice that of the jet, or the coefficient of the reentrant nozzle theoretically is 0.5 and actually is 0.53 for water, the additional 0.03 being required to balance the frictional drag on the sides of the cylindrical walls.

Considering the simple nozzle, there is a lowering of the pressure on the tapering section near the outlet which has a component in the opposite direction from that of the jet so that the unbalanced area is twice that of the throat area. This method would seem promising in investigating expansion effects with a nozzle but, unfortunately, due to the differing velocity distribution effects along the nozzle with different pressure ratios, the constant factor of 2 just mentioned is not followed for gases. However, as earlier noted, this method has been used for gases with square-edged orifices by making the assumption that the velocity, and hence pressure, distribution on the upstream face of the orifice is the same for either a liquid or a gas.*

From the above dynamic considerations, the impact of the jet on a normally disposed plate must equal the reaction of the jet. The pressure in the center of the jet where stopped is clearly that of the fluid approaching the nozzle and this forces the stream to flow outwardly from the center of the jet along the plate. This same concept explains the impact pitot tube action in converting kinetic energy back into pressure, with a coefficient of practically unity.**

5. Borda's Law of Momentum Changes at an Increase of Section.

Losses due to flow meters, generally, fall under Borda's law which serves to tie together and explain some of the flow happenings, especially with orifices, which are otherwise difficult to investigate.

With an abrupt enlargement of section a_2 to a_1, which equals a_3, where subscript 2 indicates the smaller and 1 or 3 the larger section, as in Section 4,

* E. Buckingham, Notes on the Orifice Meter, the Expansion Factor for Gases, RP 159, Bureau of Standards Journal of Research, July 1932.
** Daugherty, Hydraulics, 1925 Ed., McGraw-Hill, New York, pages 340-343.

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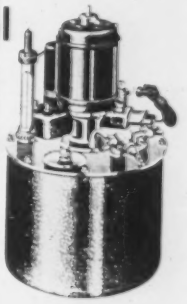

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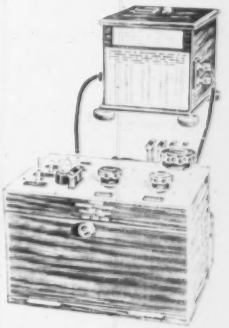

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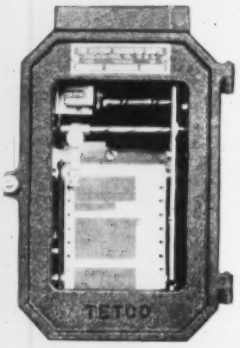

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equating forces from pressure-times-area with momentum-changing forces (of mass per second times change of velocity) one obtains the loss of head as (Borda's law)

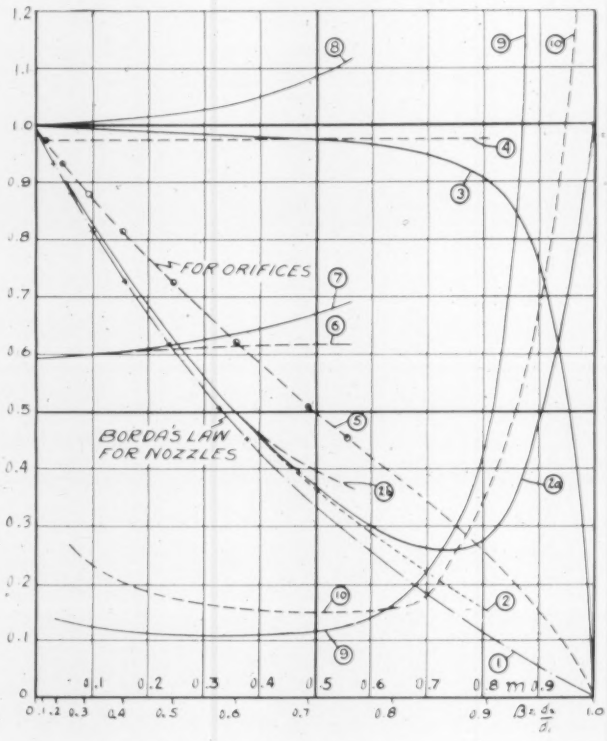
$$L = \frac{(V_2 - V_1)^2}{2g} = \left[\frac{a_1}{a_2} - 1\right]^2 \frac{V_1^2}{2g} = \left[1 - \frac{a_2}{a_1}\right]^2 \frac{V_2^2}{2g}$$

values of which are calculated in the accompanying table† and plotted against the area ratio for nozzles as line (1) of Fig. 25-15.

a_1/a_2	10	9	8	7	6	5	4	3	2
$m = a_2/a_1$	0.100	0.111	0.125	0.143	0.167	0.200	0.250	0.333	0.500
$d_2/d_1 = \sqrt{m}$	0.316	0.333	0.354	0.378	0.408	0.447	0.500	0.577	0.707
$[(1/m) - 1]^2$	81	64	49	36	25	16	9	4	1
L/H	0.818	0.800	0.778	0.750	0.714	0.667	0.600	0.500	0.333

The losses for a nozzle with a friction coefficient of unity and for a thin plate square-edged orifice are nearly the same for the same diameter ratios, e.g. using the vena contracta as the throat of the orifice. This is closely true for the usual diameter ratios, although for orifices of a diameter ratio of over 0.7, the loss is higher than would be obtained by using Borda's relation.

The friction coefficient of an actual well-shaped nozzle falls slightly below unity to a good average value of 0.975, the relation of L/H to m for such nozzles being shown on Fig. 25-15 as line (2) slightly above line (1). In practice, well-shaped nozzles follow this line for area ratios up to about 0.5 (diameter ratio of 0.7), while at higher ratios the friction coefficient of the nozzle itself drops, generally as shown on line (3), with the result that the L/H line curves away from the dotted portion of line (2), rising along line (2a), these values being fair instead of precise. For small (less than 2" throats) nozzles which are



1. L/H for nozzles, $C_f = 1.000$
2. L/H for nozzles, $C_f = 0.975$
2a. L/H for nozzles, Actual C_f
2b. L/H for small nozzles, Actual C_f
3. C_f for Venturis
4. C_f for nozzles
5. L/H for orifices
6. C for orifices
7. C_v for orifices
8. C_v/C for orifices
9. L/H for Venturi with Herschel standard length recovery cone
10. L/H for Venturi with 1/4 recovery cone

Fig. 25-15

relatively rough, line (2b) is closer than (2a) which is for nozzles having throats larger than 6" and at high Reynolds numbers, R_d of over 10^5, these generally giving substantially flat coefficients with nozzles having throats smoothly lathe finished with a round nosed tool.

Fig. 25-15 also shows L, H, C and C_v for orifices plotted against m respectively as curves 5, 6, and 7. C_v is the coefficient of the orifice equation

$$Q = C C_v Y_v \phi \frac{a_2}{\sqrt{1 - C_v^2 Y_v^2 m}} \sqrt{2gH}$$

†Partly from pages 204-206, Hughes & Safford, Hydraulics, Macmillan, New York, 1911.

may be expressed in terms of C of the hydraulic equation

$$Q = C Y_1 \frac{a_2}{\sqrt{1 - m^2}} \sqrt{2gH} = K Y_1 a \sqrt{2gH}$$

hands, where ϕ, Y_0, and Y_1 all equal unity, as

$$C_0 = \frac{1}{\sqrt{\frac{1}{K^2} - m^2}}$$

Using vena contracta taps in a 6" line with a Reynolds number, R_D, of 10^5, the values of C_0/C, computed from tables in the A.S.M.E. Fluid Meter Research Report, Part I, as are all other such values in this section, are plotted on a light line (8) which is seen to rise gently from unity with increasing values of m. Since line (6) for C is considerably flatter and straighter than line (5) for C_0, C is superior to C_0 for correlating data.

With C_1 equal to unity and using the orifice formula, the relation of $L\ H$ to m for orifices is shown by line (5), computed values being shown by circles. These same values, recomputed on the basis of the area ratio of the vena contracta to pipe, are plotted as crosses, which are seen to fall closely on the dot-dash Borda-line (1) for C_1 of unity.

Using the pipe taps ($2\frac{1}{2}$ up and 8 pipe diameters downstream of the orifice) practically amounts to using the loss as a metering head and the hydraulic coefficient for such a meter, as will be seen later, is

$$C_p = C \sqrt{H/L} = C \sqrt{\frac{1 - C^2 m^2}{1 - C m}} \epsilon \sqrt{\frac{1 + C m}{1 - C m}}$$

closely where C is the contraction coefficient and m is the area ratio of orifice to pipe. It is clear that the contraction coefficient must substantially equal the loss coefficient C_p where the orifice is much smaller than the pipe. As seen from lines 6, 7 and 8 of Fig. 25-15, the contraction coefficient is practically equal to the hydraulic coefficient C for present purposes, the contraction coefficient properly requiring that it occur in the correction for velocity of approach, while with C no such correction is made.

To have a clear picture of velocity heads, and consequently losses, it is necessary to have a proper expression for it. The velocity head

$$H = \frac{\text{total kinetic energy per second}}{\text{mass per second}} = \frac{E}{M}$$

The total kinetic energy per second

$$H = \int_0^R 2\pi r\, dr\, V\, w\, V^2/2g$$

for a circular stream where r and R are radii, V is the velocity, and w is the density. This simplifies to

$$E = (w\pi/2g)\, A_1$$

where A_1 is the area of a graph in which V^2 is plotted as ordinate against r^2 as the abscissa for a known velocity distribution. The mass per second

$$M = \int_0^R 2\pi r\, dr\, V\, w = w\pi A_2$$

where A_2 is the area of a graph in which V is plotted as ordinate against r^2 as abscissa for a known velocity distribution. Thus the true average velocity head* is simply

$$H = [(w\pi A_1)/2g]/(w\pi A_2) = (1/2g)(A_1/A_2)$$

This velocity head for non-uniform velocity distribution is generally stated as

$$H = aV^2/2g$$

The ratio $L\ H$ is plotted on curves 9 and 10 respectively for venturi tubes with the Herschel standard (about 11:1 taper) and the shorter (1:4) recovery cones.

The ratio $L\ H$ for orifices varies only a few tenths of one per cent over a range of R_D of from 2.5×10^4 to 10^7 for diameter ratios of 0.1 to 0.7. However, for venturi tubes, this ratio may be used, instead of R_D, as a basis for plotting friction coefficients C_f as on Fig. 25-16. C_f varies from slightly under unity for $L\ H = 0.11$ approximately to approach zero for $L\ H$ of about 4.

* G. E. Lyon, "Flow in Conical Draft Tubes of Varying Angles," *Transactions ASME*, Vol. 15, p. 1283, paper No. 1840.
† N. Connet's idea in the discussion of Paper No. 1886, "The Orifice Meter," by E. S. Smith, *Trans. ASME*, Vol. 45, 1923, pages 627-8.

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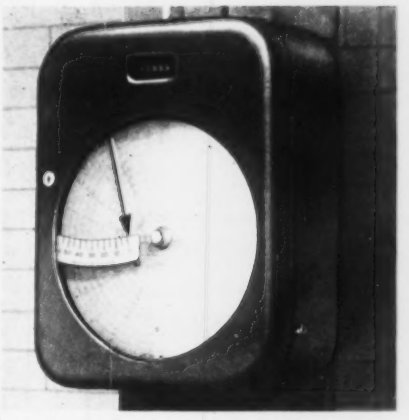

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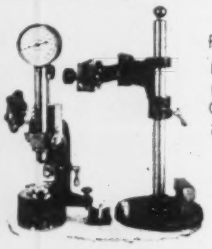

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with the Herschel standard venturi tube and for $L\ H$ of about 1.7 with the short (1:4) recovery cone. These same limiting values of $L\ H$, i.e., of the order of 4 and 1.7, are also approached as the diameter ratio approaches unity at higher Reynolds numbers. On Fig. 25-16, the heavy solid line shows tests on an

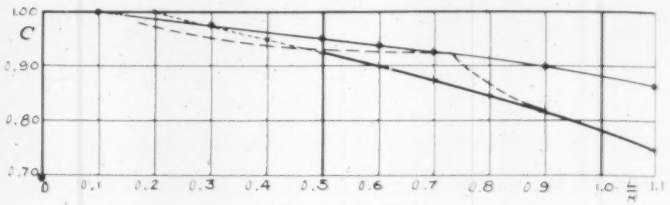

Fig. 25-16

unconventional 3" 8" by 3" 16" venturi, having a throat 3½ dia. long, of which 1½ dia. is upstream of the throat taps, an inlet cone taper of 3.3, an outlet taper of 7.3 and an unspecified overall length between the loss connections.** The approximate relation for the Herschel standard venturi tube is $C = [1 - 0.5(L\ H) - 0.1]^{1/2}$ while that for Mikita's design is $C = [1 - 0.49(L\ H) - 0.23]^{1/2}$. The dash line represents ASME tests at the University of Oklahoma on a Herschel standard venturi 4" by 2" having an inlet taper of about 3, an outlet taper of about 11, a short throat, and well rounded transition sections. The crosses and circles are calculated values, using the above formulas.

The drop from the calculated values at higher values of $L\ H$ is due to the change in the law of flow, in velocity distribution and in the corresponding α in passing from turbulent to viscous flow with α respectively changing from about unity to 2 so that the velocity head changes from $V^2/2g$ to $(2V^2/2g)$ V^2/g.

Ideally, losses are in excess of these due to pipe friction in the same length of pipe as between the loss taps used. Otherwise a fair comparison cannot be made, particularly in the case of large venturis.

With expansible fluids, the vena contracta c expands, the area of the stream section there being nearly in the ratio of $(\pi c_2/\pi c_1)^{2/n}$ to that of a stream of liquid from the same orifice 2, or of gas flowing at such a low differential as to have practically negligible expansion effects. While this relation is less closely followed for diameter ratios of over 0.5, for smaller ratios it may be used in establishing the loss and its corresponding "pipe" tap coefficients and expansion factors. Ruppel, Witte, and the present writer independently evaluated the expansion of the vena contracta at about the same time: Ruppel and Witte making the above-noted assumption and developing approximate formulas for the expansion, while the writer preferred to ascertain empirically from available data what the relation actually was. Buckingham later derived still another formula from the impulse relation as mentioned in the preceding section and separately checked such the values of such expansion empirically. The present point is that since the relation between the expansion of the vena contracta and the pressure and specific heat ratios is well established, it may be used with confidence in setting up the loss relations for pipe taps.

For orifices having nearly zero diameter ratio,

$$Y_c = Y_1 \phi = C_c/C = 1 - 0.44S\ (1 - S)$$

where C_c is the coefficient of contraction for liquid flow, C_{c_2} is that for gas flow, Y_c is the expansion factor for the vena contracta, Y_1 is expansion factor for the hydraulic formula with vena contracta taps, ϕ is that for a nozzle using the hydraulic formula and throat taps, ϕ_t being the theoretical value for well shaped nozzles as checked by experiment. Using the foregoing relation for Y_c and the theoretical expansion factor ϕ_t, one obtains a closely approximate relation for the flow with either vena contracta or pipe taps. In other words, the relation between flow and pressure is that accompanying adiabatic expansion even though the velocity energy, when converted into heat, ultimately restores the final temperature the same as the initial, i. e., an isothermal expansion.

Using the hydraulic formula for both the vc and loss taps,

$$M = CY_1 C_a a_2 \sqrt{2\Delta p/\pi c_1} = C_l Y_1 C_a a_2 \sqrt{2\Delta l/\pi c_1} \quad \ldots \quad (1)$$

from which, for liquids:

LIQUIDS $$C_l = C\sqrt{\Delta p/\Delta l} = C\sqrt{H/L} \quad \ldots \quad (2)$$

where H and L are differential heads of the liquid itself.

With a friction coefficient of unity,

$$H = (V_2^2 - V_1^2)/2g = V_2^2/2g\ (1 - C^2m^2) \quad \ldots \quad (3)$$

** J. I. Mikita, Calibration of Small Venturi Meters, *Instruments*, Vol. 9, Jan. 1936, 14.

Borda's law

$$L = (V_c - V_1)^2 2g = V_c^2 2g (1 - Cm)^2 \quad (4)$$

from (2), (3) and (4),

$$C_1 = C \sqrt{\frac{1 - C^2m^2}{1 - Cm}} = C \sqrt{\frac{1 - Cm}{1 - Cm}} \quad (5)$$

S

gases, the vena contracta expands:

$$Y_c = \frac{1 - 0.41(1 + 0.85\,m^2)\,S}{1 - 0.85(1 + m^2)S} = 1 + 0.445\,(1 + m^2)\,S \quad (6)$$

ximately.

king conditions at the vena contracta and, as development shortening ap proximations, taking the same density at the inlet and downstream taps, i. e treating the fluid as a liquid, and using the hydraulic coefficient C as nearly equal to the contraction coefficient C_c, which properly should be used. In other words, considering the vc as the throat of the orifice, CY_1m may be substituted for Cm in equations (3)–(5),

$$\frac{L}{H} = \frac{(1 - CY_1m)^2}{1 - C^2Y_1^2m^2} = \frac{1 - CY_1m}{1 - CY_1m} \quad (7)$$

And from (1), (2) and (7),

$$Y_1 = \frac{CY_1}{C_1}\sqrt{\frac{H}{L}} = Y_1\,\frac{1 - Cm}{1 - CY_1m}\sqrt{\frac{1 - C^2Y_1^2m^2}{1 - C^2m^2}}$$

$$Y_1 \sqrt{\frac{1 - Cm}{1 + Cm}\,\frac{1 - CY_1m}{1 - CY_1m}} \quad (8)$$

from which Y_1 can be readily computed.

The acoustic ratio

$$S = H P_1 k \quad (9)$$

with H and P_1 in the same units, and

$$S_1 = L P_1 k = LS H \quad (10)$$

$$\text{or } S/S_1 = H L \quad (11)$$

Thus, S_1 can be readily found from equations (7) and (11) and the corresponding values of Y_1 and S_1 plotted and compared with experimentally obtained values, e.g. those of Fig. 73 of ASME FMR-I. For recommended values of m and S, the above method is fairly satisfactory, considering the simplifying approximations introduced, although it is not as close as may be desired. For a diameter ratio of 0.6, or $m = 0.36$, and a pressure ratio of $(p_1 - p_c)/p_1 = 0.10$, for vc taps, and $(p_1 - p_c)/p_1 = 0.058$ for loss taps, the calculated loss expansion factor for air is $Y_1 = 0.975$, which is only 1% high as compared with the above-mentioned Fig. 73. Based upon values from this source,

$$Y_1 = 1 - 0.41\,(1 + 0.85m^2)\,S \quad (12)$$

for vc, flange, or corner taps, and

$$Y_1 = 1 - 0.41\,(1 + 3.16m^2)\,S \quad (13)$$

for pipe (loss) taps.

Y_1 is seen to equal Y_1 for small area ratios. However, equation (13) should be used with caution because its form differs so radically from that of equation (8). When better data, and or more extensive analyses than the above rough one, become available, it is to be anticipated that still closer results may be obtained with a formula more along the lines of equation (8) than of equation (13), but until then equation (13) may be useful and probably more accurate at usual values of m and S_1 than the more formidable equation used in plotting the above-mentioned Fig. 73. It may be noted that the effect of pipe friction with the larger values of m tends to lower Y_1 so that the calculated value more closely approaches the experimental.

However, due to such pipe friction, the expansion of the gas with loss taps follows the adiabatic relation less closely with large than with small diameter ratios. Offhand, one might think that the expansion would follow the isothermal relation with loss taps and that the expansion factor consequently could be plotted against the acoustic ratio, but this has not proved to be the case. Actually, it may be plotted against the acoustic ratio without commercially objectionable error, even for the largest diameter ratios used in recommended practice. With the plots based upon values for air, the errors for air would of course be zero and the errors for other gases would not be large since the specific heat ratio of 1.4 for air lies nearly midway between the maximum of

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